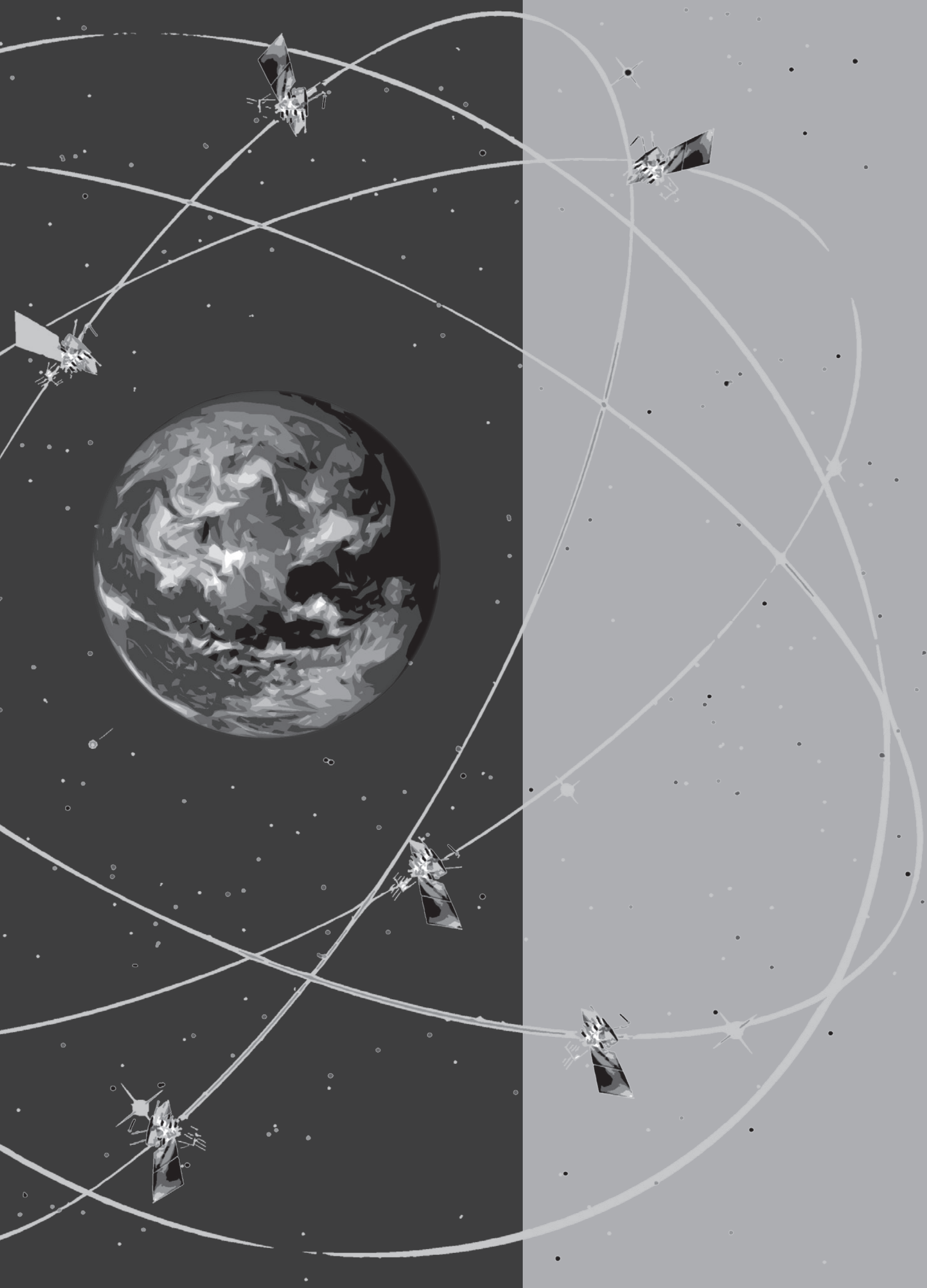
IGS INTERNATIONAL GNSS SERVICE

2013 TECHNICAL REPORT



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International GNSS Service

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International Union of Geodesy and Geophysics

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Technical Report 2013

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Abstract

Applications of the Global Navigation Satellite Systems (GNSS) to Earth Sciences are numerous. The International GNSS Service (IGS), a federation of government agencies, universities and research institutions, plays an increasingly critical role in support of GNSS–related research and engineering activities. This Technical Report 2013 includes contributions from the IGS Governing Board, the Central Bureau, Analysis Centers, Data Centers, station and network operators, working groups, pilot projects, and others highlighting status and important activities, changes and results that took place and were achieved during 2013.

This report is available online as PDF version at
ftp://igs.org/pub/resource/pubs/2013_techreport.pdf.

The IGS wants to thank all contributing institutions operating network stations, data centers or analysis centers or supporting the IGS in any other form. All contributions are welcome. They guarantee the success of the IGS also in future.

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Executive Groups

The Development of the IGS in 2013 – The Governing Board's Perspective

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1 Introduction

Since nearly 20 years the IGS provides the highest quality and openly available GNSS data, products and services for a large variety of applications that benefit the scientific community and society. This is possible with the strong support of more than 240 institutions and organizations worldwide and a large number of individuals devoting their expertise and valuable time to the IGS. The Governing Board discusses the activities of the various IGS components, sets policies and monitors the progress with respect to the agreed strategic plan using newly developed tools. The work is however done within the components. In the following sections, highlights and core activities as well as GB activities are presented.

2 IGS Highlights in 2013

A milestone in 2013 was the launch of the IGS Real-Time Service on April 1st, 2013. Already a few minutes after the official announcement by IGS-Mail the first users registered at the IGS CB caster. By the end of the year the number of new users grew to about 550. Since its launch the Service, under the coordination of Loukis Agrotis (ESA/ESOC), provided three streams of orbit and clock products with a remarkable availability of 99.7%. Significant progress has also been registered by the GB with respect to the other IGS key project Ũ the Multi-GNSS Experiment (MGEX). The MGEX network grew to some 100 multi-GNSS stations by the end of the year, tracking data is stored in a campaign directory at the global Data Centers, and five Analysis Centers are providing regular or occasional orbit and clock products.

A large effort was invested into the second reprocessing activity by the Analysis Centers, the Analysis Center Coordinator, and the Reference Frame Coordinator. Standards were defined, software packages updated in order to reanalyze 20 years of IGS tracking data with the most up-to-date models and the highest consistency. Considerable effort was also spent by the IGS CB, with essential contributions from UNAVCO, for the development of the new IGS web site and the Site Log Manager. Both were under beta-testing by the end of the year and soon ready to be launched. Finally, preparations started for the IGS Anniversary Workshop that will be held on June 23-27, 2014, in Pasadena. Rolf Dach (AIUB) as the chair of the Scientific Organizing Committee, together with Shailen Desai (JPL) and Andrzej Krankowski (UWM) developed an exciting draft program, while Allison Craddock and the IGS CB are coordinating the local facilities.

Not always in the primary focus but indeed essential for the IGS are all the operational activities, including the maintenance of the tracking network by the station operators with the support of the Network Coordinator, the data holding for free access at the Data Centers, the data analysis and operational preparation of highest precision products at the Analysis Centers, the coordination and supervision of the activities by the Product Coordinators, and finally the work contributed by the Working Groups focusing on various topics of relevance for the IGS, and the Central Bureau assuming responsibility for the general management and day-to-day operations of the IGS. Of considerable importance for the governance of the IGS is strategic planning and monitoring of the activities with respect to the Strategic Plan with the use of new monitoring tools. Finally, activities also include fostering of links with GGOS and ohter organizations, as well as the presentation of IGS activities and strategy at a number of workshops and conferences. Last but not least: We have a new IGS logo!

3 IGS Real–Time Service

The IGS Real-time Service (RTS) was launched on April 1st, 2013, after a big effort over many years. Significant developments were required in order to reach this milestone. A global real-time tracking network needed to be put in place, including configuration and management of communications and data distribution; algorithms needed to be developed; products to be generated; combined and validated; and the necessary standards and real-time formats and protocols needed to be developed. The effort was led by the Real Time WG with Mark Caissy (NRCan) as the Chair and Loukis Agrotis (ESA/ESOC) as the Analysis Coordinator. At the time of the successful launch of the RTS, three orbit and clock product streams were provided based on real-time data from some 150 globally distributed stations processed by eight Analysis Centers. Throughout the year the RTS had a remarkable performance with an availability of 99.7% demonstrating that the redundancy concept being used was indeed very robust. Since the start of the RTS until end of the year about 270 registered at the CB caster and 280 registered at the BKG caster, in addition to the 2191 users already registered at the BKG server since 2008.

4 Strategic planning

The Central Bureau under the lead of Steve Fisher collected a wealth of information in the form of Key Performance Indicators (KPI) that could be used to monitor the performance of the IGS according to our new strategic planning process. These KPI document that the IGS made progress with respect to all objectives listed in the Strategic Plan 2013-2016. The monitoring tools proved to be very valuable, and allow the GB to obtain a comprehensive overview of the actual IGS performance with respect to the Strategic Plan. As only one interesting result, the in-kind contribution received from the about 240 organizations and institutions contributing to the IGS was conservatively estimated as 10 Mio US$ per year. Some of the objectives in the Strategic Plan, in particular related to maintenance and diversification of funding sources require additional effort. Based on the input by the different components of the IGS the Strategic Implementation Plan for 2014 was established.

In 2013 the Call for Proposals for a new Analysis Center Coordinator was issued. An early identification of the next ACC allows for a smooth transition until the end of 2015, when the term of NGS hosting this important function since 2008 comes to an end.

In time for the 20th anniversary of the IGS our new logo was approved by the Board at its December meeting. The logo was designed by Prim Prim Studio, a small design company from Lithuania, and with the strong engagement of Allison Craddock from the IGS CB. The distinctive logo has the appearance of a stylized navigation satellite and is thus very appropriate. It will become associated with the IGS over the coming decade.

5 Governing Board Meetings in 2013

The IGS Governing Board met three times in 2013. GB business meetings took place on April 7th during the EGU General Assembly in Vienna and on September 4th during the IAG Scientific Assembly. The regular end-of-year meeting took place on December 8 during the AGU Fall Meeting in San Francisco. The IGS Executive Committee Ũ consisting of Urs Hugentobler, Chuck Meertens, Ruth Neilan, Chris Rizos, Tim Springer and with regular participation of Steve Fisher, Allison Craddock, and of WG Chairs as required Ũ has met eight times in 2013 by teleconference.

A summary of the GB meeting in December 2013 may be found in IGS Mail 6849. Tab. 1 lists the important events in 2013.

Table 1: IGS events in 2013

April 1	Launch of IGS Real–Time Service
April 7	GB Business Meeting in Vienna (EGU)
September 4	GB Business Meeting in Potsdam (IAG Scientific Assembly)
December 3	Issue of Request for Proposals for the next ACC
December 8	42nd GB Meeting in San Francisco (AGU)
	– Fran Boler elected as Data Center Representative
	– Laura Sanchez elected as Network Representative
	– Gary Johnston appointed GB member
	– Satoshi Kogure appointed GB member
	– Michael Coleman assigned as new Clock Product Coordinator
	– new IGS logo approved

6 Governing Board Membership

A significant change in the GB membership took place in 2013. Two positions were up for election, namely a Data Center Representative and a Network Representative as the terms of Cary Noll and Gary Johnston ended at the end of 2013. Five candidates agreed to stand in the election, which was organized by an Election Committee consisting of Chuck Meertens (Chair), Carey Noll, and Ralf Schmid. The candidates were Fran Boler, Ludwig Combrinck and Jong Uk (James) Park as Data Center Representatives, and Laura Sánchez and Graeme Blick as Network Representatives. All candidates received strong support from the Associate Members. As a result of the election Laura Sánchez (DGFI) was elected as Network Representative and Fran Boler (UNAVCO) was elected as Data Center Representative.

The Board is pleased that both Carey Noll (GSFC) and Gary Johnston (GA) continue serving as GB members, Carey Noll as Chair of the Data Center WG and Gary Johnston as a new appointed member. At the meeting Satoshi Kogure from Japan Aerospace Exploration Agency (JAXA) was also appointed to the GB. Although not representing his agency, Satoshi is very involved in QZSS and in the Asia Pacific multi-GNSS activities, as well as in the International Committee on GNSS (ICG) and thus complements the IGS GB with extensive expertise. The terms of appointed GB members Richard Wonnacott and James Park ended at the close of 2013. The GB thanks both of them for their contributions at many GB meetings over the years.

At the end of 2013 Ken Senior (NRL) stepped down as Clock Product Coordinator after many years. Ken started his work as Clock Products Coordinator and WG Chair in 2003 and since then significantly enhanced the performance of the IGS Rapid and Final timescales. At the GB meeting in December the Board approved Michael Coleman (NRL) as new Clock Products Coordinator. Mark Caissy (NRCan) stepped down as RT WG Chair at the end of 2013. Over the last ten years he was the driver for our newest product, the IGS Real-Time Service. With much enthusiasm he pushed the undertaking forward and brought it to a successful launch.

The terms of Bruno Garayt (IGN) as the Reference Frame Coordinator as well as of Nacho Romero (ESA/ESOC) as the Chair of the Infrastructure Committee drew to a close by the end of 2013. IGN as well as ESA/ESOC renewed their support and the Board unanimously agreed that Bruno Garayt and Nacho Romero continue their important functions for a further term of four years.

Several Working Group Chairs were routinely up for renewal, namely Christine Hackman (USNO), Chair of the Troposphere WG; Carey Noll (NASA/GSFC), Chair of the Data Center WG; and Ken Mac Leod (NRCan), Chair of the RINEX WG. All three are ready to continue their work for the IGS and have the support of their respective institutions. The GB unanimously renewed their terms based on their contributions Ũ well documented in the respective components reports.

Tab. 2 lists the members of the IGS Governing Board for 2013.

7 Outreach

The IGS is well represented on the GGOS Coordinating Board. It plays a leadership role in the International Committee on GNSS (ICG), in particular by co-chairing Working Group D on Reference Frames, Timing and Applications, and the International GNSS Monitoring and Assessment (IGMA) Subgroup within ICG Working Group A. In these roles the IGS participated in the ICG-8 meeting in November in Dubai. The IGS is also well-represented in the International Earth Rotation & Reference Systems Service (IERS) and in IAG Sub-Commission 1.2 on reference frames, in the RTCM SC104, and others.

IGS has been engaged in many outreach activities in 2013. The following list is a selection of presentations at international meetings and articles in geospatial magazines. As in previous years the IGS was also given visibility as session organizers of, or presenters in, IGS-related sessions at conferences such as those of the EGU in Vienna, the IAG Scientific Assembly in Potsdam, and AGU in San Francisco.

Selection of presentations at international meetings:

- European Geosciences Union General Assembly 2013, April 10, Vienna, Steigenberger, "Status and Perspective of the IGS Multi-GNSS Experiment (MGEX)"
- U.S. Institute of Navigation Pacific PNT Symposium, April 22-25, Honolulu, Hawaii, Rizos, "The IGS MGEX Experiment as a Milestone for a Comprehensive Multi-GNSS Service"
- 4th Chinese Satellite Navigation Conference, May 15, Wuhan, China, Hugentobler, "International GNSS Service - New Products for Real-Time Applications"
- EUREF Symposium 2013, May 29, Budapest, Hungary, Hugentobler, "Real-Time

and Multi-GNSS - Key Projects of the International GNSS Service"

- Hexagon International Conference, June 3-6, Las Vegas, Nevada, Rizos, "The International GNSS Service (IGS) in a Multi GNSS World"
- IGNSS 2013, July 18, Surfers Paradise, Australia, Montenbruck, "The Multi-GNSS Experiment of the International GNSS Service"
- 4th International Colloquium Scientific and Fundamental Aspects of the Galileo Programme, December 12, Prague, Czech Republic, Montenbruck "IGS-MGEX: Preparing the Ground for Multi-Constellation GNSS Science"

Selection of articles:

- Montenbruck, O., Steigenberger, P., Khachikyan, R., Weber, R., Langley, R.B., Mervart, L., Hugentobler, U.: “IGS–MGEX: Preparing the Ground for Multi–Constellation GNSS Science”, in Proceedings of the 4th International Colloquium Scientific and Fundamental Aspects of the Galileo Programme.
- Montenbruck, O., Rizos, C., Weber, R., Weber, G., Neilan, R., Hugentobler, U.: Getting a Grip on Multi–GNSS, The International GNSS Service Multi GNSS Campaign; GPS World, Vol. 24, Nr. 7.
- Rizos, C., “Multi–GNSS: Now and in the Future”, Coordinates Vol. IX, Sept. 2013
- Springer, T., “Multi–GNSS Monitoring”, Inside GNSS, Nov./Dec. 2013

Reports, Brochures, Flyers:

- IGS Strategic Plan 2013–2016
- IGS Progress Report 2008–2012
- IGS Overall Brochure
- IGS Quality of Service Fact Sheet
- IGS Real–Time Service Fact Sheet

8 Outlook

The year 2014 already promises the next highlight, our Anniversary Workshop on June 22-27 at JPL in Pasadena, CA, celebrating 20 years of service. We are all looking forward to this important event. In 2014 we will also see the launch of a new IGS website and Site Log Manager. Rapid progress is expected in the Multi-GNSS Experiment as it prepares the IGS for a seamless integration of the new and upcoming GNSS constellations into its processing streams and products. To accomplish our goals we seek the support of new groups willing to contribute to this effort. Preparations for launching Full Operational

Capability in the Real-Time Service are underway. The reprocessing campaign will be terminated providing to the users and to ITRF2013 consistent IGS products covering 20 years and adhering to the most up-to-date models and standards.

The IGS GB thanks all participants and supporters of the IGS for their efforts invested in the past year. Only with the continuous efforts of the network operators, operators of data centers and analysis centers, the product coordinators, WG, PP and committee chairs and members, the Central Bureau, and the continuous support by numerous institutions worldwide the IGS is able to serve a large user community with the provision of the highest quality GNSS products.

Table 2: IGS Governing Board Members 2013 (*: voting members, EC: Executive Committee)

Member	Institution	Country	Function
Urs Hugentobler (EC)*	Technische Universität München	Germany	Board Chair, Analysis Center Representative
Zuheir Altamimi*	Institut National de l'Information Géographique et Forestière	France	IAG Representative
Felicitas Arias	Bureau International des Poids et Mesures	France	BIPM/CCTF Representative
Claude Boucher*	Institut National de l'Information Géographique et Forestière	France	IERS Representative
Carine Bruyninx*	Royal Observatory of Belgium	Belgium	Network Representative
Mark Caissy	Natural Resources Canada	Canada	Real–Time WG Chair
Yamin Dang*	Chinese Academy of Surveying and Mapping	China	Appointed
Shailen Desai*	Jet Propulsion Laboratory	USA	Analysis Center Representative
Steve Fisher	IGS Central Bureau, Jet Propulsion Laboratory	USA	IGS Secretariat
Bruno Garayt*	Institut National de l'Information Géographique et Forestière	France	Reference Frame Coordinator, IGS Representative to IAG Sub–commission 1.2
Jake Griffiths*	NOAA, National Geodetic Survey	USA	Analysis Center Coordinator
Christine Hackman	United States Naval Observatory	USA	Troposphere WG Chair
Gary Johnston*	Geoscience Australia	Australia	Network Representative
Andrzej Krankowski	University of Warmia and Mazury in Olsztyn	Poland	Ionosphere WG Chair
Ken MacLeod	Natural Resources Canada	Canada	IGS/RTCM RINEX WG Chair
Chuck Meertens*	UNAVCO	USA	Appointed
Oliver Montenbruck	DLR/German Space Operations Center	Germany	Multi–GNSS WG Chair
Ruth Neilan (EC)*	IGS Central Bureau, Jet Propulsion Laboratory	USA	Director of IGS Central Bureau, Secretary
Carey Noll*	Goddard Space Flight Center	USA	Data Center Representative, Data Center WG Chair
James Park*	Korean Astronomy and Space Science Institute	South Korea	Appointed
Chris Rizos (EC)*	University of New South Wales	Australia	President of IAG since July 2011 (before: appointed)
Ignacio Romero	ESA/European Space Operations Centre	Germany	Infrastructure Committee Chair
Stefan Schaer	Federal Office of Topography	Switzerland	Bias and Calibration WG Chair
Ralf Schmid	Deutsches Geodätisches Forschungsinstitut	Germany	Antenna WG Chair
Tilo Schöne	Deutsches GeoForschungs–Zentrum Potsdam	Germany	TIGA WG Chair
Ken Senior*	Naval Research Laboratory	USA	Clock Product Coordinator
Tim Springer (EC)*	ESA/European Space Operations Centre	Germany	Analysis Center Representative, IGS Representative to IERS, Chair of Associate Members Committee
Richard Wonnacott*	Chief Directorate: National Geo–spatial Information	South Africa	Appointed
Marek Ziebart	UniversityCollegeLondon	UK	Space Vehicle Orbit Dynamics WG Chair

IGS Technical Report 2013
Central Bureau

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1 Introduction

The IGS Central Bureau (CB) is hosted at the California Institute of Technology/Jet Propulsion Laboratory and is funded by NASA. The Central Bureau supports IGS management focusing on two principal functions: 1) executive management of the service, including international coordination and outreach, and 2) coordination of IGS infrastructure, including the IGS tracking network and information management systems. Specific responsibilities of the Central Bureau are outlined in the IGS Terms of Reference: http://igs.org/organization/orgindex.html. Accomplishments during 2013, as well as plans for 2014, are outlined within this report.

2 Executive Management

- Developed 2013–2016 Strategic Plan and monitoring progress.
- Supported 2013 Associate Member selection and Governing Board election.
- Supported Governing Board meetings in Vienna, Potsdam and San Francisco.
- Supported Executive Committee activities and teleconferences approximately every other month.
- Supported IAG 150th Anniversary meetings and activities.
- Local coordination of 2014 IGS workshop was initiated.

- Compiled official service reports for IERS and IAG.
- Terms of Reference were reviewed resulting in a number of proposed changes presented to the Governing Board.

3 Project Support, Committee and Working Group Participation

- Supporting key activities in all areas.
- Supporting Real–time Service launch. Operate RTS product distribution center and website, support RTS user registrations, user support.
- Supporting M–GEX and outreach efforts with Multi–GNSS.
- Supporting development of multi–GNSS monitoring capabilities through the International Committee on GNSS (ICG).
- Supporting Infrastructure Committee activities.
- Participating on Antenna, RINEX, Reference Frame Working Groups.

4 Develop Funding

- Significant coordination of Space Geodetic Program for NASA funding of CB.
- Development of overall strategic goals and monitoring of Key Performance Indicators (KPI) strongly relates to funding development for entire IGS.
- The IGS Institute business plan was drafted and presented to the Governing Board at the December meeting.
- An Industry sponsor program was drafted to develop sponsors to support 2014 Workshop and other activities.

5 Monitor progress on Strategic Plan

- The annual Component Report template was modified to collect progress information.
- An end of year progress assessment was completed. A dashboard of Key Performance Indicators is being developed and will be posted on the IGS website in early 2014.

- Working groups were requested to self assess the impacts of their groups on strategic goals as part of the year–end progress assessment.
- A target service performance specification has been drafted. Monitoring data is included in the KPI dashboard.

6 Website/Marketing Communications

- A new IGS logo was developed and approved by the Governing Board.
- The first phase of website modernization was almost completed at year–end. Features include: modern content management system improves maintainability, web 2.0 features built–in, simplified navigation, new logo and branding, hosted external from JPL to allow unrestricted global access, bibliography, knowledgebase, search, video section, and social media integration.
- Next phase development will facilitate third party content management for the Working Groups.
- All IGS brochures and distribution materials have been updated.

7 Network Infrastructure and Information

- Site Log Manager (SLM) database application was released in Beta.
- An improved network page with extended metrics is published on website: http://igs.org/network/network.php
- Coordinating with IC to address various network issues.
- Better defining/streamlining procedures for accepting new stations into the IGS.
- UNAVCO resources have been fully integrated into station management and user support function.
- Finalized and published the IGS Site Guidelines.
- CB caster (http://rt.igs.org) is hosting the IGS combination streams IGS01, IGS02, IGS03, and RTCM3EPH01.
- CB caster (http://rt.igs.org) is accepting approximately 115 streams from station providers where about 75% of are typically transmitting data.
- Deleted 14 decommissioned stations from the network.
- Automated the process of updating the igs08.atx to allow Antenna Working Group

Chair to publish the standard w/o any delay.

- Changed the CMP designation to BDS throughout the IGS network and the products generated from the CB.
- Added 71 equipments to the rcvr_ant.tab and their available sketches with their ARP definitions in the antenna.gra.
- Supported MGEX to grow to 98 stations.
- Accepted the following stations to IGS Network:

  AREV – Arequipa, Peru

  BNOA – Benoa, Indonesia

  BSHM – Haifa, Israel

  BTNG – Bitung, Indonesia

  CKIS – Rarotonga, Cook Islands

  DYNG – Dionysos, Greece

  FTNA – Maopo'opo, Wallis and Futuna

  KOUG – Kourou, France (French Guiana)

  MOIU – Eldoret, Kenya

  PALV – Palmer Station, Antarctica

  WARK – Warkworth, New Zealand

8 User support

- Knowledgebase system has been implemented at CB.
- The CB user support burden has been compounded principally by introduction of the Real–time Service (RTS), and also by the Multi–GNSS project.
- CB Mails numbered 2,915 in 2013 (2,801 in 2012).
- Formal trouble ticketing and resolution application are being investigated as needs grow.

9 Meetings/Outreach

The following meetings that relate to IGS were supported by the CB in 2013.

Table 1: CB meetings in 2013

Date	Location	Meeting
December 2013	San Francisco, CA	IGS Governing Board meeting and related meetings, GGOS GB, GIAC, BNC Meetings
December 2013	Washington DC	PNT Advisory Panel meeting
November 2013	Dubai, UAE	8th Meeting of the International Committee on Global Navigation Satellite Systems (ICG) WG on Reference Frames, Timing and Applications International GNSS Monitoring and Assessment (IGMA)
September 2013	Pasadena, CA	CEOS SIT Technical Workshop – local organization supported by GGOS/IGS
September 2013	Tokyo, Japan	Remote attendance of World Data System Scientific Committee Meeting
September 2013	Nashville, TN	Programmatic meetings on GNSS monitoring and IGS real–time services in conjunction with ION
August 2013	Potsdam, Germany	IAG General Assembly, IGS Governing Board and related meetings
July 2013	Cambridge, UK	Cambridge Summit and UN Global Geospatial Information Management (UN GGIM)
May 2013	Washington DC	PNT Advisory Panel Meeting
April 2013	Paris, France	8th Meeting of Scientific Committee of the World Data Systems
April 2013	Vienna, Austria	Remotely organized and attended programmatic meetings organized around EGU (GB, GGOS, etc.)
March 2013	Langley, Virginia	28th Meeting of CEOS Strategic Implementation Team
February 2013	Vienna, Austria	UNOOSA committee meeting on the Peaceful Use of Outer Space
January 2013	San Diego, CA	ION International Technical Meeting RTCM Committee Meeting

10 Policy Interactions

The Central Bureau has supported a number of policy interactions on behalf of IGS in 2013.

- NASA policy participation.
- UN–ICG participation.
- UN–GGIM GGRF WG participation.
- WDS participation.
- Many interactions through GGOS and GIAC.

11 Standards Supported

The Central Bureau has supported development/maintenance of a number of important standards activities affecting IGS in 2013.

- Support IC in site and networks standards.
- Support Antenna Working Group in maintaining IGS antenna files.
- Support RINEX WG.
- Support RTS interests in RTCM SC–104.
- Interchangeability/interoperability monitoring Standard supported through ICG.

12 Publications

- 2013–2016 IGS Strategic Plan
- 2008–2012 IGS Progress Report
- 2012 IGS Technical Report section
- 2012 IERS Annual Report
- 2011–2013 IAG Mid–term Report

13 Plan for 2014

- Executive Support: Continue fulfilling the IGS executive responsibilities resulting in effective management and governance of the service. Provide local organization to 20th anniversary Workshop.
- Project Support, Committee and Working Group Participation: Continue supporting all WG activities. Emphasis on achieving RTS FOC.
- Develop funding: Develop industry sponsor program. Evaluate ways to recover cost of operating service.
- Monitor progress on Strategic Plan: Update IGS dashboard at least once during year.
- Website/Marketing and Communications: Phase II website development – improve content, add 3rd party development workflows for WGs.
- Coordinate network infrastructure and information: finalize SLM, convert selected RTS stations to full IGS stations.
- Service Performance Targets: Continue monitoring defined service availability.
- User support: Improve efficiency in handling many user support requests by implementing the Site Log Manager application (SLM), a web based Knowledge Base (KB), and trouble ticketing technologies.
- Outreach: Emphasis on IGMA and UN–GGRF–WG activities.
- Refine the network with more robust stations in key areas providing more GNSS coverage.

Part II

Analysis Centers

Center for Orbit Determination in Europe (CODE)

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1 The CODE consortium

CODE, the Center for Orbit Determination in Europe, is a joint venture of the following four institutions:

- Astronomical Institute, University of Bern (AIUB), Bern, Switzerland,
- Federal Office of Topography swisstopo, Wabern, Switzerland,
- Federal Agency of Cartography and Geodesy (BKG), Frankfurt a. M., Germany, and
- Institut für Astronomische und Physikalische Geodäsie, Technische Universität München (IAPG, TUM), Munich, Germany.

The operational computations are performed at AIUB whereas reprocessing activities are usually carried out at IAPG, TUM. All solutions and products are produced with the latest development version of the Bernese GNSS Software (Dach et al. 2007).

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2 CODE products available to the public

A wide variety of GNSS solutions based on a rigorously combined GPS/GLONASS data processing scheme is computed at CODE. The products are made available through anonymous ftp:
`ftp://ftp.unibe.ch/aiub/CODE/` or `http://www.aiub.unibe.ch/download/CODE/`
An overview of the files is given in Tab. 1.

In the table the following abbreviations are used:

`yyyy`	Year (four digits)	`ddd`	Day of Year (DOY) (three digits)
`yy`	Year (two digits)	`wwww`	GPS Week
`yymm`	Year, Month	`wwwwd`	GPS Week and Day of week

Table 1: CODE products available through anonymous ftp.

CODE *final* products available at ftp://ftp.unibe.ch/aiub/CODE/yyyy/

`yyyy/CODwwwwd.EPH.Z`	CODE final GNSS orbits
`yyyy/CODwwwwd.ERP.Z`	CODE final ERPs belonging to the final orbits
`yyyy/CODwwwwd.CLK.Z`	CODE final clock product, clock RINEX format, with a sampling of 30 sec for the satellite and reference (station) clock corrections and 5 minutes for all other station clock corrections
`yyyy/CODwwwwd.CLK_05S.Z`	CODE final clock product, clock RINEX format, with a sampling of 5 sec for the satellite and reference (station) clock corrections and 5 minutes for all other station clock corrections
`yyyy/CODwwwwd.SNX.Z`	CODE daily final solution, SINEX format
`yyyy/CODwwwwd.TRO.Z`	CODE final troposphere product, troposphere SINEX format
`yyyy/CODGddd0.yyI.Z`	CODE final ionosphere product, IONEX format
`yyyy/CODwwwwd.ION.Z`	CODE final ionosphere product, Bernese format
`yyyy/CODwwww7.SNX.Z`	CODE weekly final solution, SINEX format
`yyyy/CODwwww7.SUM.Z`	CODE weekly summary file
`yyyy/CODwwww7.ERP.Z`	Collection of the 7 daily CODE-ERP solutions of the week
`yyyy/COXwwwwd.EPH.Z`	CODE final GLONASS orbits (for GPS weeks 0990 to 1066; 27-Dec-1998 to 17-Jun-2000)
`yyyy/COXwwww7.SUM.Z`	CODE weekly summary files of GLONASS analysis
`yyyy/CGIMddd0.yyN.Z`	Improved Klobuchar–style ionosphere coefficients, navigation RINEX format
`yyyy/P1C1yymm.DCB.Z`	CODE monthly P1−C1 DCB solution, Bernese format, containing only the GPS satellites
`yyyy/P1P2yymm.DCB.Z`	CODE monthly P1−P2 DCB solution, Bernese format, containing all GPS and GLONASS satellites
`yyyy/P1P2yymm_ALL.DCB.Z`	CODE monthly P1−P2 DCB solution, Bernese format, containing all GPS and GLONASS satellites and all stations used
`yyyy/P1C1yymm_RINEX.DCB`	CODE monthly P1−C1 DCB values directly extracted from RINEX observation files, Bernese format, containing the GPS and GLONASS satellites and all stations used
`yyyy/P2C2yymm_RINEX.DCB`	CODE monthly P2−C2 DCB values directly extracted from RINEX observation files, Bernese format, containing the GPS and GLONASS satellites and all stations used

Table 1: CODE products available through anonymous ftp (cont).

CODE *ultra–rapid* products available at ftp://ftp.unibe.ch/aiub/CODE

COD.EPH_U	CODE ultra–rapid GNSS orbits
COD.ERP_U	CODE ultra–rapid ERPs belonging to the ultra–rapid orbit product
COD.TRO_U	CODE ultra–rapid troposphere product, troposphere SINEX format
COD.SUM_U	Summary of stations used for the latest ultra–rapid orbit
COD.ION_U	Last update of CODE rapid ionosphere product (1 day) complemented with ionosphere predictions (2 days)
COD.EPH_5D	Last update of CODE 5–day orbit predictions, from rapid analysis, including all active GLONASS satellites

CODE *rapid* products available at ftp://ftp.unibe.ch/aiub/CODE

CODwwwwd.EPH_R	CODE rapid GNSS orbits
CODwwwwd.EPH_P	CODE 24–hour GNSS orbit predictions
CODwwwwd.EPH_P2	CODE 48–hour GNSS orbit predictions
CODwwwwd.EPH_5D	CODE 5–day GNSS orbit predictions
CODwwwwd.ERP_R	CODE rapid ERPs belonging to the rapid orbits
CODwwwwd.ERP_P	CODE predicted ERPs belonging to the predicted 24–hour orbits
CODwwwwd.ERP_P2	CODE predicted ERPs belonging to the predicted 48–hour orbits
CODwwwwd.ERP_5D	CODE predicted ERPs belonging to the predicted 5–day orbits
CODwwwwd.CLK_R	CODE rapid clock product, clock RINEX format
CODwwwwd.TRO_R	CODE rapid troposphere product, troposphere SINEX format
CODwwwwd.SNX_R.Z	CODE rapid solution, SINEX format
CORGddd0.yyI	CODE rapid ionosphere product, IONEX format
COPGddd0.yyI	CODE 1–day or 2–day ionosphere predictions, IONEX format
CODwwwwd.ION_R	CODE rapid ionosphere product, Bernese format
CODwwwwd.ION_P	CODE 1–day ionosphere predictions, Bernese format
CODwwwwd.ION_P2	CODE 2–day ionosphere predictions, Bernese format
CODwwwwd.ION_P5	CODE 5–day ionosphere predictions, Bernese format
CGIMddd0.yyN_R	Improved Klobuchar–style coefficients, RINEX format
CGIMddd0.yyN_P	1–day predictions of improved Klobuchar–style coefficients
CGIMddd0.yyN_P2	2–day predictions of improved Klobuchar–style coefficients
CGIMddd0.yyN_P5	5–day predictions of improved Klobuchar–style coefficients
P1C1.DCB	CODE sliding 30–day P1−C1 DCB solution, Bernese format, containing only the GPS satellites
P1P2.DCB	CODE sliding 30–day P1−P2 DCB solution, Bernese format, containing all GPS and GLONASS satellites
P1P2_ALL.DCB	CODE sliding 30–day P1−P2 DCB solution, Bernese format, containing all GPS and GLONASS satellites and all stations used
P1P2_GPS.DCB	CODE sliding 30–day P1−P2 DCB solution, Bernese format, containing only the GPS satellites
P1C1_RINEX.DCB	CODE sliding 30–day P1−C1 DCB values directly extracted from RINEX observation files, Bernese format, containing the GPS and GLONASS satellites and all stations used
P2C2_RINEX.DCB	CODE sliding 30–day P2−C2 DCB values directly extracted from RINEX observation files, Bernese format, containing the GPS and GLONASS satellites and all stations used
CODE.DCB	Combination of P1P2.DCB and P1C1.DCB
CODE_FULL.DCB	Combination of P1P2.DCB, P1C1.DCB (GPS satellites), P1C1_RINEX.DCB (GLONASS satellites), and P2C2_RINEX.DCB

Note that as soon as a final product is available the corresponding rapid, ultra–rapid, or predicted products are removed from the anonymous FTP server.

Table 2: CODE final products available in the product areas of the IGS data centers.

Files generated from three–day long–arc solutions:

CODwwwwd.EPH.Z	GNSS ephemeris/clock data in daily files at 15–min intervals in SP3 format, including accuracy codes computed from a long–arc analysis
CODwwwwd.SNX.Z	GNSS daily coordinates/ERP/GCC from the long–arc solution in SINEX format
CODwwwwd.CLK.Z	GPS satellite and receiver clock corrections at 30–sec intervals refering to the COD–orbits from the long–arc analysis in clock RINEX format
CODwwwwd.CLK_05S.Z	GPS satellite and receiver clock corrections at 5–sec intervals refering to the COD–orbits from the long–arc analysis in clock RINEX format
CODwwwwd.TRO.Z	GNSS 2–hour troposphere delay estimates obtained from the long–arc solution in troposphere SINEX format
CODwwww7.ERP.Z	GNSS ERP (pole, UT1−UTC) solution, collection of the 7 daily COD–ERP solutions of the week in IGS IERS ERP format
CODwwww7.SUM	Analysis summary for 1 week

Files generated from pure one–day solutions:

COFwwwwd.EPH.Z	GNSS ephemeris/clock data in daily files at 15–min intervals in SP3 format, including accuracy codes computed from a pure one–day solution
COFwwwwd.SNX.Z	GNSS daily coordinates/ERP/GCC from the pure one–day solution in SINEX format
COFwwwwd.CLK.Z	GPS satellite and receiver clock corrections at 30–sec intervals refering to the COF–orbits from the pure one–day analysis in clock RINEX format
COFwwwwd.CLK_05S.Z	GPS satellite and receiver clock corrections at 5–sec intervals refering to the COF–orbits from the pure one–day analysis in clock RINEX format
COFwwwwd.TRO.Z	GNSS 2–hour troposphere delay estimates obtained from the pure one–day solution in troposphere SINEX format
COFwwww7.ERP.Z	GNSS ERP (pole, UT1−UTC) solution, collection of the 7 daily COF–ERP solutions of the week in IGS IERS ERP format
COFwwww7.SUM	Analysis summary for 1 week

Other product files (not available at all data centers):

CODGddd0.yyI.Z	GNSS 2-hour global ionosphere maps in IONEX format, including satellite and receiver P1−P2 code bias values
CKMGddd0.yyI.Z	GNSS daily Klobuchar-style ionospheric (alpha and beta) coefficients in IONEX format
GPSGddd0.yyI.Z	Klobuchar-style ionospheric (alpha and beta) coefficients from GPS navigation messages represented in IONEX format

Note that the COD–series is identical with the files posted at the CODE's aftp server, see Tab. 1.

Since GPS week 1706, CODE has generated a pure one–day solution (label "COF") in addition to the traditional three–day long–arc solution (label "COD"). The result files from both series are submitted to the IGS data centers hosting the products. The related files are listed in Tab. 2.

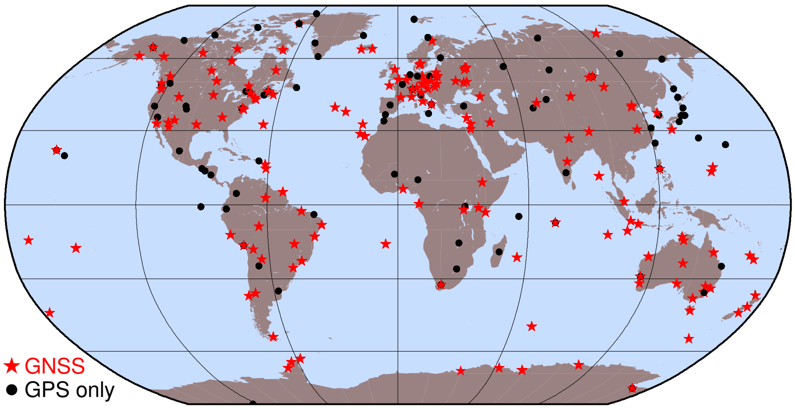


Figure 1: Network used for the GNSS final processing at CODE by the end of 2013.

The network used by CODE for the final processing is shown in Fig. 1. Nearly 80% of the stations support GLONASS (red stars).

3 Changes in the daily processing for the IGS

The CODE processing scheme for daily IGS analyses is constantly subject to updates and improvements. The last technical report was published in Dach et al. (2013).

In Section 3.1 we give an overview of important development steps in the year 2013. Section 3.2 reports on the improvements in the CODE ultra-rapid product generation and Section 3.3 provides details on the update of the final clock product computation.

3.1 Overview of changes in the processing scheme in 2013

Tab. 3 gives an overview of the major changes implemented during the year 2013. Details on the analysis strategy can be found in the IGS analysis questionnaire at the IGS Central Bureau (`ftp://igs.org/igscb/center/analysis/code.acn`).

Several other improvements not listed in Tab. 3 were implemented, too. Those mainly concern data download and management, sophistication of CODE's analysis strategy, software changes (improvements), and many more. As these changes are virtually not relevant for users of CODE products, they will not be detailed on any further.

Table 3: Selected modifications of the CODE processing in 2013.

Date	DoY/Year	Description
27-Feb-2013	054/2013	R26 was tracked by several stations for three days (054 to 056): 25 GLONASS or 32+25=57 GNSS satellites
28-Feb-2013	055/2013	Daily check of GLONASS frequency channel numbers Alarming scheme established (as soon as an anomaly gets detected for doy -1)
09-Jun-2013	160/2013	If less than 10 complete RINEX files for the 5 sec clock densification are available (to be used as potential reference clocks) also incomplete RINEX files (with missing epochs in the result files) are allowed to be used as reference clock
23-Jun-2013	174/2013	Weekly ERP files are merged from daily results
08-Jul-2013	188/2013	New ERP file generation used for IGS ultra-rapid submission
11-Jul-2013	192/2013	New ERP file is also used for orbit prediction
14-Jul-2013	195/2013	Change orbit model for *final product line*: • change JPL Ephemeris from `DE405` to `DE421` • enable Albedo model according to Rodriguez-Solano et al. (2012) • enable Antenna thrust (GPS: block-specific according to `http://acc.igs.org/orbits/thrust-power.txt`; GLONASS: assumed averaged value of 100 W) • disable the a priori radiation pressure model (Springer et al. 1999) Improved observation identification allowing for potential quarter-cycle identfication implemented for *all product lines*
19-Jul to 02-Aug-2013		No VMF coefficients available from TU Vienna: • 19-Jul to 28-Jul-2013 (DoY 200-209) coefficients from University of New Brunswick (based on NCEP) used • 29-Jul to 02-Aug-2013 GPT/GMF used for rapid products (final again with coefficients from Vienna)
20-Aug to 30-Aug-2013		Relocation of the University's Linux cluster into another building; all IGS-related activities are managed on a backup system
05-Sep-2013		Submission from the nominal system recovered after system tests and back-synchronisation
13-Sep-2013	256/2013	Make sure that accuracy code zero in precise orbit files cannot appear for a valid satellite
20-Sep-2013	263/2013	Accuracy code cleaned up in precise orbit files for weeks 1706 to 1756 on CODE's FTP server
02-Oct-2013	275/2013	Allow for independent reference clocks for 30 s and 5 s final clock products
01-Nov-2013	305/2013	Change orbit model for *rapid/ultra-rapid product line*: • change JPL Ephemeris from `DE405` to `DE421` • enable Albedo model according to Rodriguez-Solano et al. (2012) • enable Antenna thrust (GPS: block-specific according to `http://acc.igs.org/orbits/thrust-power.txt`; GLONASS: assumed averaged value of 100 W) • disable the a priori radiation pressure model (Springer et al. 1999)
03-Nov-2013	307/2013	High-rate (30 s) clock solution uses exclusively stations from "regular" daily RINEX archives; RINEX files from real-time streams are only used for ultra-high-rate (5 s) clock product generation (before, real-time based RINEX files have occasionally been used for generating the high-rate clock product)
10-Nov-2013	314/2013	Allow more iterations for screening the observation file for the phase-based interpolation of the 5 min clock solutions to 30 s and 5 s respectively
12-Nov-2013	316/2013	Start submitting ultra-rapid products (orbits, ERPs) generated with the new scheme, see Section 3.2

3.2 Updating the CODE ultra-rapid product generation

Comparing the ultra-rapid orbits from CODE with the IGS combined product and the solutions from other analysis centers by a 7-parameter Helmert transformation, large rotations, especially around the z-axis, were present since a long time.

In a first step, an inconsistent use of Earth rotation parameters (ERP) was identified. Different sets were used for the integration and prediction of the ultra-rapid orbits in the inertial frame on the one hand and for the transformation back to the terrestrial frame on the other hand. This problem could be solved by using one single set of ERPs covering the time span for all affected calculations. The impact of this change made at 11-July-2013 can be seen in a significant reduction of the scatter of the z-rotation parameter in Fig. 2.

In a second step, a redesign of the ultra-rapid product generation was realized. Now, one set of consistent orbital elements and ERPs is derived from combining normal equations. The orbits are represented in the best possible way over the observed time interval with two days of observations, followed by an integration over the last observed 48 hours. Nine empirical parameters are set up for the predicted part of the ultra-rapid product. The ERPs are parameterized with 24 hours linear pieces in the observed and a linear extrapolation for the predicted part. The new products have been submitted since 12-Nov-2013 and were again included with weight in the combination a few days later. This second change reduced the z-rotation even more (see Fig. 2) and improved the consistency to the other ultra-rapid contributions which can be recognized in the decrease of the RMS and weighted RMS of the CODE solution compared to the combined IGS ultra-rapid product (see Fig. 3).

As another benefit from the new procedure, CODE now provides ERP files not only for the midnight and noon but for all ultra-rapid update versions (00 h, 06 h, 12 h and 18 h).

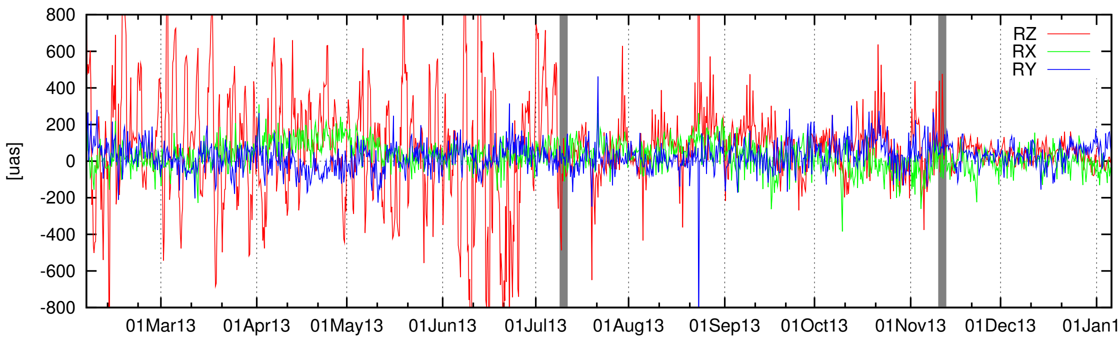


Figure 2: Rotation parameters for the z-, x- and y-axis from the Helmert transformation between CODE's submitted ultra-rapid orbits and the combined IGS product. The switch to consistent ERPs took place at 11-Jul-2013, the complete redesign at 12-Nov-2013.

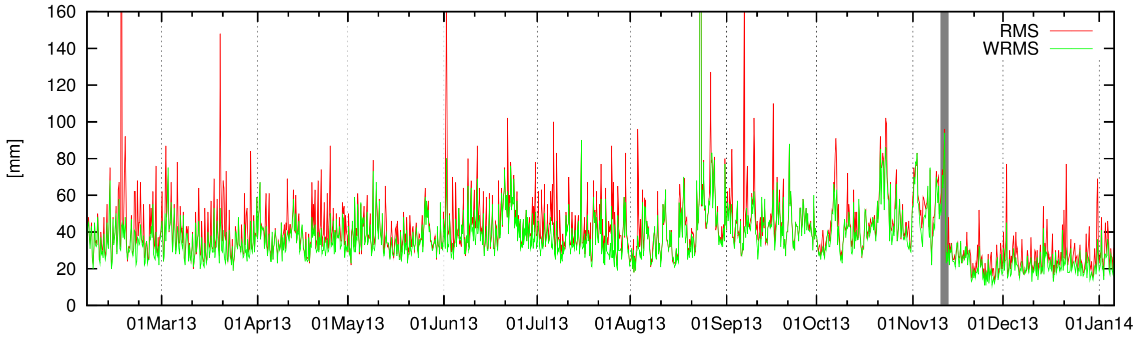


Figure 3: RMS and weighted RMS (WRMS) of the CODE ultra-rapid orbits derived from the combination of the IGS ultra-rapid product. At 12-Nov-2013 the first results from the redesigned ultra-rapid procedure were submitted.

3.3 Experience with RINEX-files based on real-time streams

Over several weeks in Summer 2013, the IGS final clock combination revealed some problems with the contribution from CODE. Many stations were excluded from the combination as they were exhibiting an abnormal behaviour compared to solutions from other contributing analysis centers and therefore the combined solution.

After some investigations it was found that the problem was due to the different contents of the RINEX files either downloaded directly as daily RINEX file with a sampling of 30 s or constructed from the 15-minutes RINEX files with the 1 Hz high–rate sampling based on real-time stream data. Although it seems to be legitimate to expect that the data should be strictly the same (apart maybe for some gaps due to networking issues), using one file upon the other may produce significantly different results for the same station[1]. The effect of these differences in the RINEX files on the solution is illustrated in Fig. 4

[1]Note, none of the stations have indicated by the `NULLANTENNA` antenna type that the antenna phase center corrections have already been applied before streaming the data.

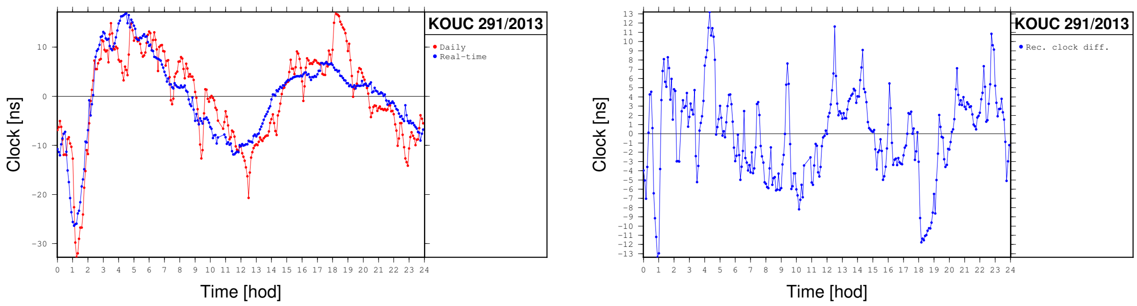


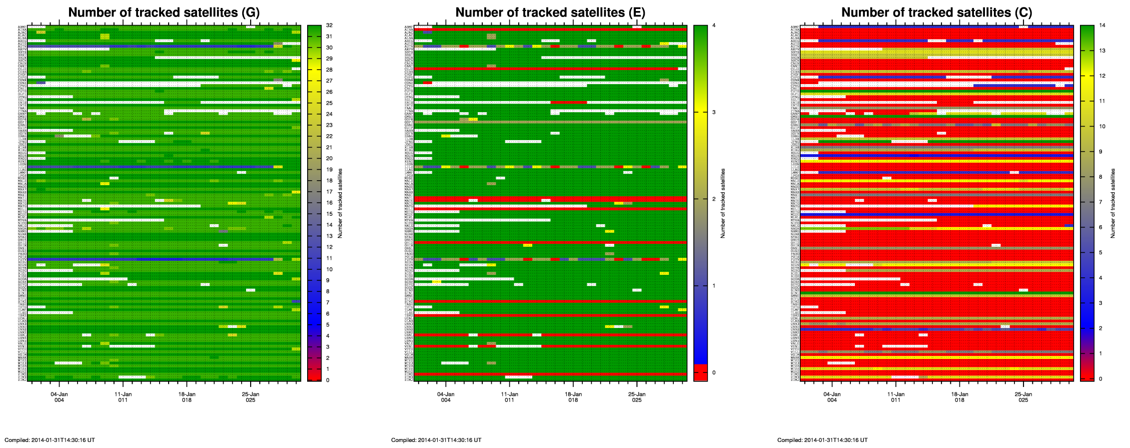
Figure 4: Receiver clock corrections for site KOUC on day 291 of year 2013 estimated using a daily RINEX file stemming from daily/hourly dumps and from real-time data flow (left) and the difference between the two solutions (right).

which displays the receiver clock correction estimates for station KOUC on day 291 of year 2013 as obtained when processing the data files in precise point positioning mode. Differences up to 13 ns could be observed on that day.

CODE is using the 1 Hz high–rate sampling RINEX files for the densification of the 30 s clock products to 5 s. Until this problem was identified, CODE was using indifferently RINEX files produced from daily/hourly dumps or from a real-time data flow. The clock generation procedure was adjusted in order to guarantee that the real-time data is only used to densify the clocks down to 5 s but not for generating the 30 s products. The massive rejection of CODE solutions in the IGS combination has stopped since then.

4 CODE contribution to the IGS–MGEX campaign

Since 2012 CODE contributes to the IGS "Multi GNSS EXperiment" (MGEX) with the main goal to gain experience with the RINEX3 data format and the integration of the new GNSS Galileo into existing processing chains and into the Bernese GNSS Software. CODE has established an extensive raw data monitoring to RINEX3 data. The RINEX3 data monitoring bases on a XML–inventory that is generated as soon as the file is downloaded and copied into our database. All further requests for information or statistics only access the XML–database, which is much more efficient than scanning each individual RINEX observation file for each individual request. Some standard extracts from the XML–inventory are freely available at ftp://ftp.unibe.ch/aiub/mgex/. Some of the



(a) GPS (b) Galileo (c) BeiDou

Figure 5: Number of available satellites per GNSS in the RINEX3 files (available in ftp://ftp.unibe.ch/aiub/mgex/plots); one line corresponds to one station.

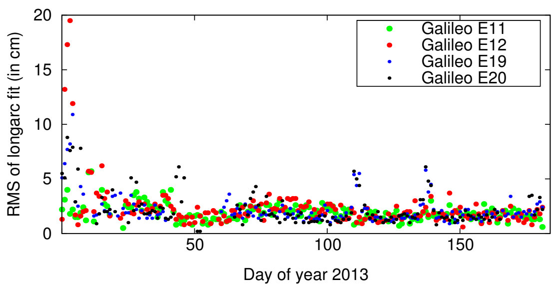


Figure 6: Three-day long arc fit through CODE Galileo orbits of consecutive days estimating for the six initial conditions, three constant and three once–per–revolution terms defined according to Beutler et al. (1994).

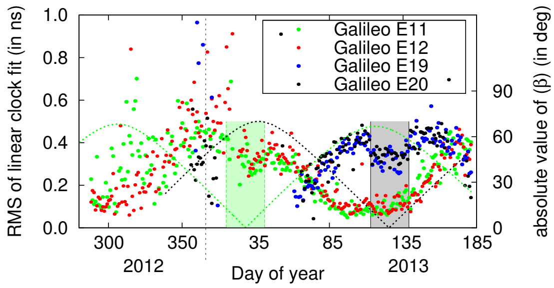


Figure 7: RMS of daily linear fit through estimated epoch-wise Galileo satellite clocks (big dots). The shaded areas mark the eclipsing seasons of E11, E12 (green) and of E19, E20 (black). The curves show the absolute value of the elevation of the Sun w.r.t. the satellite's orbital planes (β) with the same color code as the boxes.

information is even available in a graphical form, see Fig. 5 as examples. Apart from RINEX3 files of the MGEX project meanwhile also numerous non-MGEX stations are included in the database. Thanks to the increasing number of MGEX stations and the consideration of stations belonging to the EUREF Permanent Network (EPN), the number of monitored stations providing RINEX3 data is meanwhile exceeding one hundred.

This data is used along with "regular" RINEX2 data in a fully-integrated, triple-GNSS, double-difference processing, which delivers orbit positions (middle day of a 3-day long arc) of all active GPS, GLONASS, and Galileo satellites. The main changes during 2013 are the inclusion of the two additional Galileo IOV satellites launched in 2012 and the introduction of a station selection for the RINEX3 stations. An evaluation of the orbit quality is provided in Fig. 6 . The time series of generated CODE MGEX orbits currently spans from GPS-week 1690 (DOY 150/2012) to 1763 (DOY 299/2013). A newly established processing chain solves for epoch-wise GPS and Galileo satellite clock corrections in a zero-difference processing, based on the same data set as used for the double-difference solution. The time series of Galileo clock corrections currently spans from GPS-week 1710 (DOY 288/2012) to 1763 (DOY 299/2013).

In order to support the IGS community with Galileo products and allow comparisons with other groups' results, the CODE MGEX products are available at ftp://cddis.gsfc.nasa.gov/gnss/products/mgex (solution ID *com* stands for CODE-MGEX). The next goals are the inclusion of BeiDou into the CODE MGEX processing, the extension of the *com* orbit and clock time series, and the analysis of these extended time series (e.g., systematic beta-angle dependency of the estimated Galileo satellite clock corrections, as shown in Fig. 7).

5 CODE contribution to IGS repro2

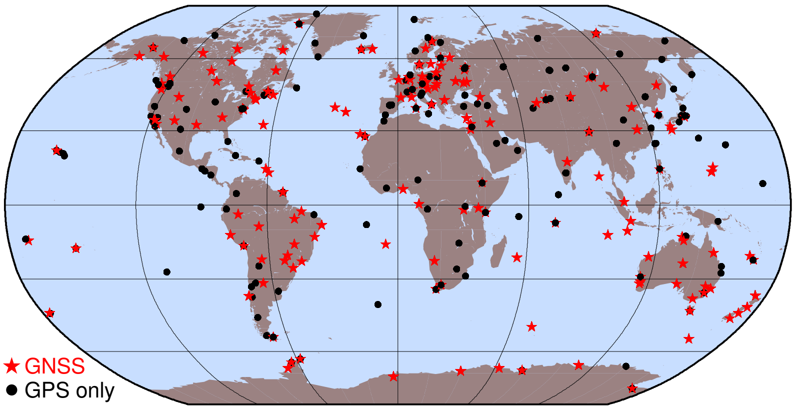
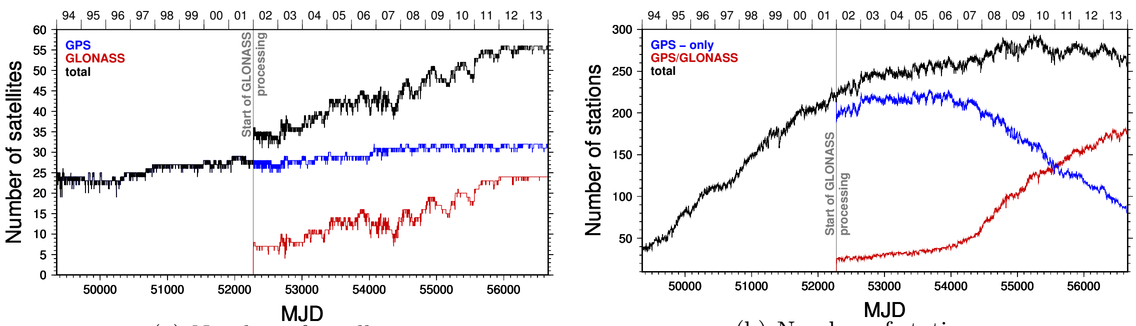


Figure 8: Network used for the GNSS reprocessing from CODE.

CODE contributes with a new reprocessing series to the IGS repro2 initiative. The effort has started from RINEX observation files to review the station selection (see Fig. 8). The interval from the beginning of 1994 (GPS week 0730) to the end of 2013 (GPS week 1773) is covered. For the first years a GPS-only solution has been generated whereas starting with the year 2002 (GPS week 1147) a fully combined GPS/GLONASS solution was computed. Some more statistical information is provided in the plots of Fig. 9.

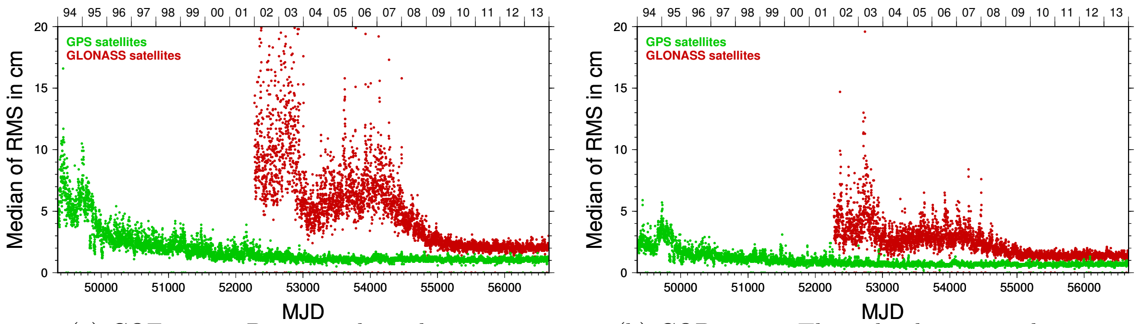
The re-processing follows the strategy from the operational CODE final processing scheme as it was in Summer 2013. It generally follows the IERS conventions 2010 (Petit and Luzum 2010) as well as the guidelines from the IGS (http://acc.igs.org/reprocess2.html). As the operational solution series from CODE, the submission of the solution to the IGS server at CDDIS will include a pure one-day (COF) as well as the corresponding three-day long-arc (COD) solution. A comparison of the quality (median of the RMS per GNSS) of fitting three consecutive days of the orbit solution is given in Fig. 10 . The long-arc series



(a) Number of satellites

(b) Number of stations

Figure 9: Statistical information on the CODE reprocessing result



(a) COF series: Pure one-day solutions

(b) COD series: Three day long-arc solutions

Figure 10: Median from the RMS of a three-day long arc fit through orbits of consecutive days of the CODE reprocessing solution

(COD) will also be published on the CODE's FTP server (ftp://ftp.unibe.ch/aiub/REPRO_2013/) in early 2014. The publication of the reprocessing series will include the file ftp://ftp.unibe.ch/aiub/REPRO_2013/CODE_REPRO_2013.ACN containing a detailed description of the models used.

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NRCan Analysis Center Report 2013

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1 Introduction

In 2013, the Geodetic Survey Division (GSD) of Natural Resources Canada (NRCan) changed its name to the Canadian Geodetic Survey (CGS) and merged within the Surveyor General Branch (SGB). This report addresses the major product changes and events that occurred within NRCan during the year 2013.

2 Review of 2013

Readers are referred to the Analysis Coordinator website (http://acc.igs.org) for historical combination statistics of the NRCan–AC products. There were no major changes made to NRCan–AC Rapid and Final core products in 2013. However, a few changes to the Ultra–Rapid processing strategy are worth mentioning.

2.1 GNSS Ultra–Rapid Products

Although GNSS Rapid/Final orbit and clock products have been produced for more than two years, our Ultra–Rapid solution was still a 'GPS–only' solution until early September 2013. The Ultra–Rapid GNSS implementation required several changes and careful planning in order to keep the same product quality and availability. Our ultimate goal was to generate 30s GNSS clocks on an hourly basis to satisfy our CSRS–PPP clients processing GNSS kinematic data. At the end of 2013, we were able to generate GNSS orbits on an hourly basis but due to computer resources constraints, we are currently able to generate 30s GNSS clocks only every 3h, i.e. at 00h, 03h, 06h, ... and 21h. For the remaining hours, 30s 'GPS–only' clocks are generated. Our first official contribution to the IGS Ultra–Rapid GLONASS combination (IGV) was on September 9, 2013, hour 12 (i.e. emu17571_12).

Table 1: Main characteristics of NRCan Ultra–Rapid Products Generation

Characteristics		**Before 2013 September 09 (emu17571_12)** ‘**GPS only**’	**From 2013 September 09 (emu17571_12)** **GPS/GLONASS**
Station Clusters	Orbit	1 x 50 stations	3 x 30 stations
	Clock	1 x 45 stations	1 x 45 stations
Interval(1)	Sp3	15 min	15 min
	Clk	30 sec	30 sec
Cycle(2)	Orbit	Hourly	Hourly (GNSS)
	Clock	Hourly	Every 3h for **_00 _03 _06 _09..._21 (GNSS)**
			Hourly for **_01 _02 _04 _05 _07 _08..._22_23 (‘GPS only’)**
Latency(3)	Orbit	Less than 1h	Less than 1h15 **(GNSS)**
	Clock	Less than 1h30	Less than 2h for **_00 _03 _06 _09..._21 (GNSS)**
			Less than 1h30 for **_01 _02 _04 _05 _07 _08..._22 _23 (‘GPS only’)**

(1) Product intervals.

(2) Processing cycle.

(3) Latency from the last available data.

Tab. 1 shows the main characteristics of the new NRCan GNSS Ultra–Rapid products (EMU). Fig. 1 and Fig. 2 show the Ultra–Rapid GPS and GLONASS orbit precision during 2013. The graphs are divided in two parts: a 0–24h estimated portion and a 24–48h predicted portion. Each portion is divided into 3h bins to better see the orbit behavior when predicted time increases. The NRCan Ultra–Rapid clock precision is shown in Tab. 2. For completeness, NRCan Rapid and Final products are also included.

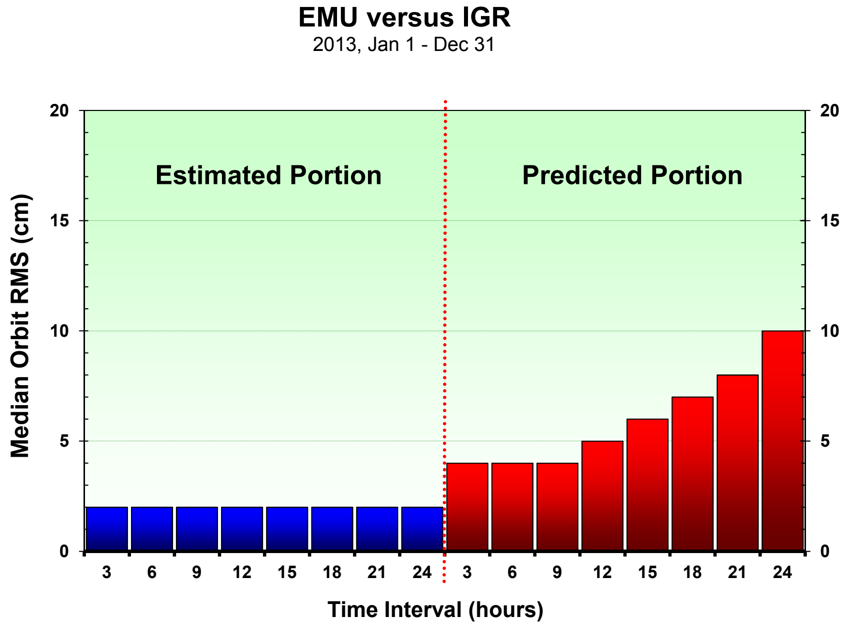

Figure 1: GPS Ultra–Rapid Orbit Median RMS for 2013.

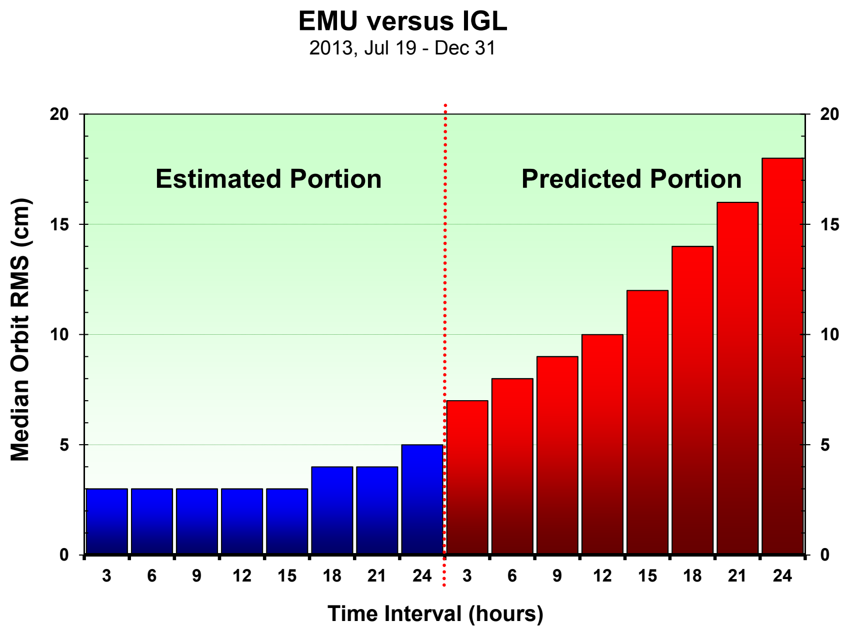

Figure 2: GLONASS Ultra–Rapid Orbit Median RMS for 2013.

Table 2: Orbit and Clock Median RMS of NRCan–AC Products for 2013

Product		**Orbits[1] (cm)**		**Clocks[2] (ns)**	
		GPS	GLONASS	GPS	GLONASS
EMU estimated (00–24h)[3]		2	2	0.09	0.08[4,5]
EMU predicted[3]	00–03 h	4	7	Not meaningful!	
	03–06 h	4	8		
	09–12 h	5	10		
	21–24 h	10	18		
EMR Rapid and Final [3]		2.0	4.0	0.07	0.08[4]

(1) Orbit RMS after applying a 7–parameter Helmert transformation.
(2) Clock RMS after proper clock alignment.
(3) Comparison against IGR for GPS and IGL for GLONASS.
(4) Comparison against ESA Final products after proper clock alignment and individual satellite bias removal.
(5) Better RMS than GPS due to comparisons made on a satellite by satellite basis.

3 Ionosphere and DCB Monitoring

Daily global ionosphere maps using nearly 400 GPS stations are being generated internally and are expected to be submitted to IGS in 2014. Near real–time ionosphere maps continue to be generated internally both in the form of near real–time spherical harmonic coefficients and since day 300, 2013 also as daily IONEX files containing 96 maps per day. During 2013, the number of high–rate stations being processed for near real–time ionosphere map generation has increased to about 165. GPS P1–P2, P1–C1 and P2–C2 as well as receiver specific P1–C1 DCBs are estimated daily.

Schematic regional and global ionospheric irregularity maps from GPS phase rate statistics (Ghoddousi-Fard et. al 2013) based on RT–IGS stations are generated internally in near real–time. A historical database of these statistics is continuously accumulated for on–going scintillation studies.

Reference

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The ESA/ESOC IGS Analysis Center

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1 Introduction

The IGS Analysis Center of the European Space Agency (ESA) is located at the European Space Operations Center (ESOC) in Darmstadt, Germany. The ESA/ESOC Analysis Center has been involved in the IGS since its very beginning in 1992. In this report we give a summary of the IGS related activities at ESOC in 2013.

2 Overview 2013

2.1 Routine Products

The ESA/ESOC IGS Analysis center contributes to all the core IGS analysis center products, being:

- Reprocessed Final GPS products (repro2)
  - Provided from 1995 to 2013
  - Based on 24–hour solutions using 150 stations GPS–only, until 2008
  - Based on 24–hour solutions using 110 stations GPS+GLONASS, from 2009
  - Consisting of Orbits, Clocks (300s), daily SINEX coordinates, and EOPs
  - Clocks with 30s sampling are also generated but not made publicly available
- Final GNSS (GPS+GLONASS) products
  - Provided weekly, normally on Friday after the end of the observation week

  - Based on 24–hour solutions using 150 stations
  - True GNSS solutions obtained by simultaneously and fully consistently processing of GPS and GLONASS measurements, using a total of around 55 GNSS satellites
  - Consisting of Orbits, Clocks (30s), daily SINEX coordinates and EOPs, and Ionosphere
- Rapid GNSS (GPS+GLONASS) products
  - Provided daily for the previous day
  - Available within 3 hours after the end of the observation day
  - Based on 24–hour solutions using 110 stations
  - True GNSS solutions obtained by simultaneously and fully consistently processing of GPS and GLONASS measurements, using a total of around 55 GNSS satellites
  - Consisting of Orbits, Clocks, Ionosphere, and EOPs
  - Rapid SINEX coordinates and EOPs available as well
- Ultra–Rapid GNSS (GPS+GLONASS) products
  - Provided 4 times per day covering a 48–hour interval; 24 hours of estimated plus 24 hours of predicted products
  - Available within 3 hours after the end of the observation interval which start at 0, 6, 12, and 18 hours UTC
  - Based on 24 hours of observations using 110 stations
  - True GNSS solutions obtained by simultaneously and fully consistently processing of GPS and GLONASS measurements, using a total of around 55 GNSS satellites
  - Consisting out of Orbits, Clocks, and EOPs
  - Separate Ionosphere estimates and predictions
- Real–Time GNSS services
  - Generation of two independent real–time solution streams
  - Analysis center Coordination
  - Generation and dissemination of the IGS Real Time Combined product stream
- GNSS Sensor Stations

  - A set of 10 globally distributed GNSS sensor stations
  - Station data available in real–time with 1 second data sampling

Besides these core products ESA is very active in different working groups. Most notably are our efforts in the Real–Time Service where besides being one of the analysis centers we are also responsible for the analysis center coordination. Also our efforts in the scope of MGEX, the antenna calibarations and satellite orbit modeling working groups are significant.

An up to date description of the ESA IGS Analysis strategy may always be found at: ftp://dgn6.esoc.esa.int/products/esa.acn

2.2 Product Changes

The main changes in our processing in 2013 were the following:

- Improved reference frame alignment and consistency between the different products
- Upgrade of the ESA/ESOC GNSS Sensor Station network
- Some minor modifications were made in the handling of the GPS–GLONASS inter-system biases
- Integration of Ionosphere estimation into the *NAPEOS software* allowing for GPS+GLONASS based ionosphere estimation

2.3 Product Highlights

The main highlight of the ESA/ESOC Analysis center products is that they are one of the best products available from the individual IGS analysis centers. Secondly the ESA products are one of the most complete GNSS products. In fact ESA was the first IGS analysis center to provide a consistent set of GNSS orbit *and* clock products. Our GNSS products constituted the very first products that could, and are, used for true GNSS precise point positioning. In particular for this purpose, the sampling rate of our final GPS+GLONASS clock products is 30 seconds.

Another special feature of the ESA products is that they are based on completely independent 24 hour solutions. Although this does not necessarily lead to the best products, as in the real world the orbits and EOPs are continuous, it does provide a very interesting set of products for scientific investigations as there is no aliasing and no smoothing.

An other unique feature is that our rapid products are, besides being one of the best, also one of the most timely available products. Normally our GNSS rapid products are available within 2 hours after the end of the observation day whereas the official GPS–only IGS products become available only 17 hours after the end of the observation day, a very significant difference.

In 2013 we have made some small modifications in the initialization and alignment of the GPS–GLONASS Intersystem biases (ISB's). The ISB values are now initialized in our preprocessing using the broadcast orbit information from both GPS and GLONASS. In this way the estimated GLONASS clocks remain aligned to the GLONASS broadcast clocks. Consequently the ISB values reflect to a large extend the time difference between the GPS and GLONASS time frames.

In the scope of 2013 we improved our reference frame alignment and the consistency between our different products. Our orbit and clock products now come from the same process based on the same reference frame realisation. Thanks to changes in the *NAPEOS* 3.7 version, which we started to use in November 2012, we are now also able to use just a subset of the stations for the reference frame alignment. The improved alignment of our products is clearly visible in the IGS combination, in particular the rotations. So our orbit, clock and SINEX products are now all 100% consistent which was not the case prior to this change. This change took effect in GPS week 1730. However, we noticed that the absense of translational constraints did significantly impact the sigma of our clock products. To avoid this negative influence from our improved reference frame alignment we have introduced translational constraints from GPS week 1737.

3 Reprocessing Activities

ESA/ESOC has participated in the first IGS reprocessing efforts (repro1) for the IGS contribution to the realisation of the International Terrestrial Reference Frame 2008 (ITRF2008) and will also participate in the reprocessing for the ITRF2013. For this reprocessing effort ESA will process all historic GNSS data of the IGS from 1994 to 2013. In this reprocessing the years 1994 to 2008 are reprocessed using only GPS observations, but from 2009 onwards the reprocessing fully includes the GLONASS observations and thus provides true GNSS solutions.

The products from the first ESA official reprocessing efforts, based on the ITRF2005 reference frame, are available from the official IGS data centers with the label "es1". The most recent ESA reprocessing products, based on the ITRF2008, are available from the official IGS data centers with the label "es2".

An interesting difference between our es1 and es2 reprocessing is that, as mentioned before, from 2009 onwards our es2 products are GNSS products. Also for our es2 products we do generate 30 second clock estimates. We produce these high–rate clock products because we are also very active in processing GNSS data from Low Earth Orbiting (LEO) receivers. For LEO processing high–rate clocks are very much needed to get accurate orbits based when using the well–known PPP approach for precise orbit determination.

4 GNSS Sensor Station Upgrade

ESA/ESOC is operating a network of globally distributed GNSS sensor stations, supporting internal and external projects (i.e. GRAS GSN, IGS, ESA Space Tracking Stations) as well as distributing the data for the scientific community (IGS and EUREF).

Until 2010 the ESOC GNSS sensor stations were limited to tracking either GPS or GPS and GLONASS. In recent years we have seen the start of the evolution of the existing GNSS and the emergence of new constellations. For the existing GNSS new satellites and signals are becoming available to the user segment, including new civilian signals for GPS (L2C and L5), CDMA modulation for GLONASS (L3). The completely new constellations that are starting to emerge are the European Galileo, the Japanese QZSS, and the Chinese BeiDou system.

Thus at ESA/ESOC we recognized that our ESOC GNSS sensor station network needed to be upgraded with state–of–the–art technology. A dedicated assessment was made, trading off between the technical requirements and the commercial market costs of the GNSS equipment required for the upgrade. This resulted in the procurement of 25 Septentrio PolaRx4 receivers and 25 Septentrio Choke Ring MC antennas, for which a deployment schedule was drafted in early 2012. This upgrade should allowed ESOC to keep its high–level of quality and reliability in GNSS operations and increased the data availability. The upgrade has been replacing the station equipment of the current ESOC GNSS network but also expanded the number of stations in order to enhance the geographical coverage and provide better depth of coverage for all the GNSS constellations. With the data of our stations we participate in the MGEX project providing Rinex 3 files with data from GPS, GLONASS, Galileo, BeiDou, and QZSS.

Fig. 1 shows the status of the ESOC GNSS sensor stations as of January 2014. Of the existing 10 GNSS sensor stations 7 were upgraded in 2012 to multi–GNSS receivers and antennas. The remaining 3 (KIRU, REDU and MAL2) were upgraded in the 1st, 3rd and 4th quarter of 2013, respectively. In addition, a Septentrio PolaRx4 replaced the multi–GNSS JAVAD Delta receiver at MGUE in the 4th quarter of 2013, yielding a fully homogenous receiver network. Advances were also made for the installation of a new GNSS station at ESA's Santa Maria (Azores) site, expected to be operational in the 1st quarter of 2014.

During 2013 agreements with several third parties were negotiated to install GNSS stations in Japan, Russia, New Zealand, Malaysia, Thailand, with the objective of expanding the ESA/ESOC GNSS network. Negotiations with third parties in U.S.A, India, U.A.E and Canada have also been initiated, but are still in a preliminary stage.

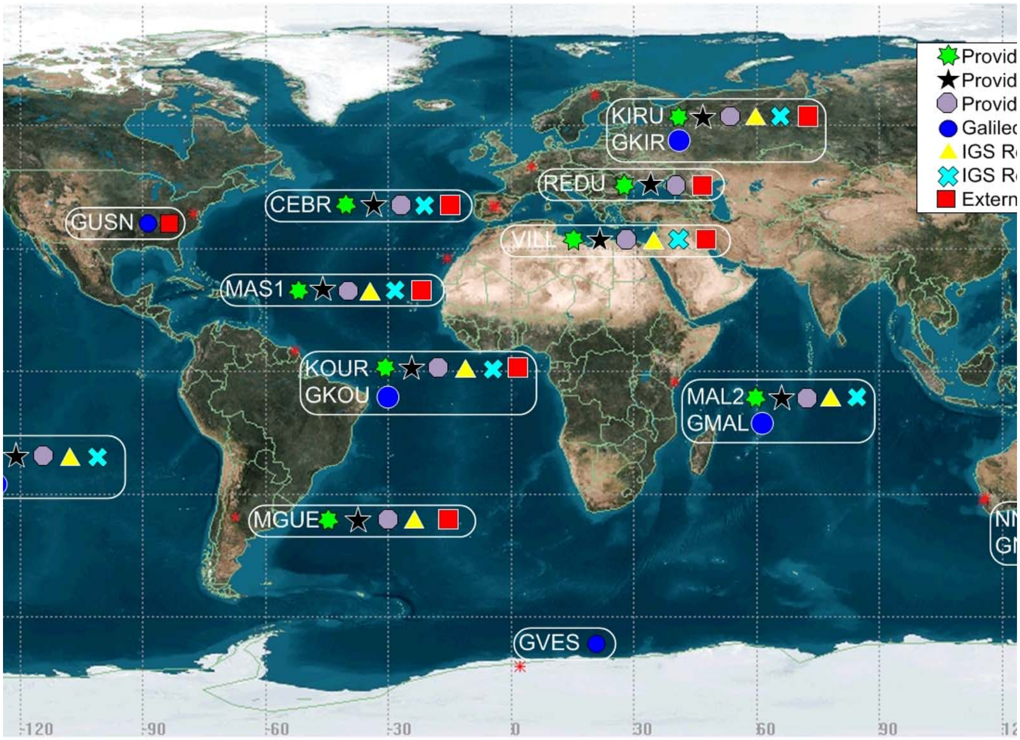

Figure 1: Status of the ESOC GNSS sensor stations as of January 2014.

5 Real Time Activities

On of the major achievements in the Real Time area in 2013 was that in April the IGS Real Time Pilot project transitioned into the IGS Real Time Service.

Over the last 10 years, ESOC has embarked on a program to build a Real Time GNSS software and network (receiver) infrastructure. RETINA (system for REal TIme NAvigation) has been modeled based on ESOC's experiences in Real Time satellite control systems and includes many of the elements for data processing, archiving and visualisation that are common to such systems. ESOC is utilising this infrastructure by participating in the IGS Real Time Service, assuming the roles of Real Time Analysis center, RT Observing Station Data Provider and Analysis center Coordinator (ACC). In the latter role, ESOC has been generating and disseminating the IGS Real Time Combination stream after processing the Real Time solutions from up to ten Analysis centers.

Included in the combination solutions are two streams generated by the ESOC Real Time Analysis center. One of these uses orbit information generated by the *NAPEOS software*, Springer (2009), which is operated under RETINA scheduling control and provides orbit updates every 2 hours. The second ESOC solution stream uses the IGS rapid orbit product, which is updated every 6 hours.

Participation in the IGS Real Time activities has stimulated the involvement of ESOC in the development of standards and formats for GNSS data and products. ESOC has been instrumental in the decision of the IGS to join the Radio Technical Commission for Maritime Services (RTCM), which is the primary standards setting organisation for Real Time GNSS services. NRCan and ESOC are the two agencies that represent the IGS at the RTCM meetings. Work with the RTCM has focused on the following areas:

- Development of standards and formats for transmission of multi–constellation observations in Real Time (RTCM–MSM)
- Development of standards and formats for the transmission of Real Time orbit and clock products (RTCM–SSR)

In addition, the IGS took a high–level decision to form a joint RTCM–IGS working group for the further development of the RINEX observation format. The terms of reference of this WG have been negotiated by ESOC and approved by the IGS Governing Board and by the RTCM.

The highlight of the (2013) Real Time ACC activities in 2013 was the launch of the official IGS Real Time service. ESOC will retain the ACC role in this service. In order to ensure a high availability for this service, combination processes are now running simultaneously at two servers external to ESOC, in the UK and in Canada (NRCan).

6 Ionosphere Modeling Activities

ESA/ESOC contributes with IONEX products to the IGS Ionosphere Working Group since its inception in 1998, initially with daily global ionospheric TEC maps in final mode (11 days latency). ESA/ESOC's activities for the ionosphere in the frame of the IGS since 2004 can briefly be summarised as follows:

- Spring 2004: Start routine delivery of daily global ionospheric TEC maps in rapid mode (1 day latency)
- December 2005: Start routine delivery of TEC maps in 2–hour time resolution, i.e. since then each ESA IONEX file provides 13 TEC and RMS maps per day
- September 2009: Commence submission of IONEX files containing 1 and 2 days ahead predicted TEC maps in 2–hour time resolution
- February 2009 – January 2010: ESA Study: GNSS Contribution to Next Generation Global Ionospheric Monitoring (Feltens (2009) and Feltens (2010))
- July 2010: Commence combination of predicted Ionosphere Associate Analysis centers (IAACs) TEC maps and submission of combined predicted IGS IONEX files in 2 hour time resolution
- February 2011: Commence submission of ESA IONEX files with 1–hour time resolution
- January 2013: The IONMON became an integral part of ESOC's *NAPEOS software* allowing for GPS+GLONASS based ionosphere estimation

ESOC employs the Ionosphere Monitoring Facility (IONMON) for its ionosphere processing. IONMON algorithms were initially devoted to single layer approaches. Since 1999, investigations were undertaken into the direction of 3D ionosphere modelling. Starting with an extended Chapman profile approach, in the subsequent years the concept of a multilayer modelling was developed, combining empirical surface functions to describe the horizontal structures of the ionosphere with vertical profile functions, which should, to some limited extent, also allow for a physical interpretation of results. It was foreseen that this new modelling should process TEC data from GNSS combined with observed electron density profiles from different sources, namely CHAMP, F3/COSMIC and ionosonde in least squares fits. In relation to these IONMON developments, from March 2009 to January 2010 the ESA Study *"GNSS Contribution to Next Generation Global Ionospheric Monitoring"* was conducted, Feltens (2009) and Feltens (2010), working out recommendations for a new ionosphere monitoring system, identifying potential users, and practical and scientific applications in terms of, among others:

- Potential ionospheric observation data sources, e.g., TEC from GNSS and radio beacons, LEO topside TEC, electron density profiles from LEO radio occultation, ionosondes, and more

- Near–Real–Time (NRT) and Real–Time (RT) suitability
- Predictability of the ionosphere's state
- Physical interpretability

In 2013, IONMON became an integral part of ESOC's *NAPEOS software*. The inclusion into *NAPEOS* enables the IONMON to nearly double the number of ground stations that can be processed. In addition, the IONMON can now process further GNSS data than only GPS, e.g. GLONASS and Galileo.

6.1 Current Activities

ESOC's actual ionosphere model development efforts are directed to 3D modelling, where the concept had to be changed from the least squares fitting of TEC and electron density data into a model comprising a combination of vertical and horizontal functions, to an approach in which TEC and electron density observables from different sources will be assimilated into a background model. It turned out that, in spite of including F3/COSMIC and CHAMP electron densities in addition to GNSS TEC observables, the data coverage is not yet dense enough to perform reliable and stable least squares fits. The mathematical algorithms for this new 3D assimilation approach were recently worked out and documented in an ESOC–internal technical note (currently still draft). At the moment the new assimilation approach is coded, based on these algorithms, as new component of *NAPEOS*. From its design, the assimilation scheme shall also enable NRT and RT processing and upgrade time resolutions down to several minutes, i.e. simple, fast and robust algorithms are required.

Once the implementation of the new assimilation approach into *NAPEOS* has been successfully concluded, ESOC's ionosphere processing will be switched over from the current single layer modelling to this new 3D modelling technique. This will then also concern ESOC's ionosphere products delivered to the IGS, e.g. new aspects such as 3D IONEX. The implementation of a more sophisticated Iono prediction scheme at ESOC will be an important future topic too. In parallel to the tasks described above, activities are ongoing to establish a new model for the plasmasphere in a cooperative effort with the German Aerospace Center (DLR) in Neustrelitz, Germany. This plasmasphere model will then complement the new 3D assimilation approach.

7 Summary

The European Space Operations center (ESOC) of the European Space Agency (ESA) Analysis Center has continued to produce "best in class" products for the IGS in 2013. Practially all products are generated using the Navigation Package for Earth Orbiting Satellites (*NAPEOS*) software. *NAPEOS* is a state of the art software that is highly accurate, very efficient, robust and reliable. It enables ESA/ESOC to deliver the high quality products as required for the IGS but also for the other space geodetic techniques DORIS and SLR. This is important because besides being an IGS Analysis center, ESA/ESOC is also an Analysis center of the IDS and the ILRS.

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GFZ ANALYSIS CENTER OF IGS
Annual Report for 2013

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1 Summary

During 2013 the standard IGS product generation was continued with minor changes in the software *EPOS–8*. A switch from weekly to daily SINEX files was performed and new 30–sec clock products were generated.

End of 2013 the processing for the 2^{nd} IGS Reprocessing campaign was nearly finished.

The capability to process in addition to GPS and GLONASS also Galileo and BeiDou data was demonstrated with the available M–GEX data.

2 Products

The list of products provided by GFZ is summarized in Tab. 1.

3 Data processing and latest changes

EPOS–8 is following the IERS Conventions 2010 (Petit and Luzum 2010). Recent changes in the processing are listed below in Tab. 2. The station network used in the processing is shown in Fig. 1. For the IGS Final, Rapid and Ultra Rapid about 200, 110, and 95 sites are used, respectively, whereas the sites providing GLONASS data is steadily increasing. Some processing related informations are given in Tab. 3.

Table 1: List of products provided by GFZ AC

Final	(GLONASS since week 1579)
gfzWWWD.sp3	Orbits for GPS/GLONASS satellites
gfzWWWD.clk	5–min clocks for stations and 30–sec clocks GPS/GLONASS satellites
gfzWWWD.snx	Daily SINEX files
gfzWWW7.erp	
gfzWWW7.sum	Summary file incl. Inter–Frequency Code Biases (IFB) for GLONASS
gfzWWWD.tro	1–hour ZPD estimates
Rapid	(GLONASS since week 1579)
gfzWWWD.sp3	Orbits for GPS/GLONASS satellites
gfzWWWD.clk	5–min clocks for stations and GPS/GLONASS satellites
gfzWWWD.erp	
Ultra	(every 3–hours; provided to IGS every 6 hours, GLONASS since week 1603)
gfuWWWD.sp3	Adjusted and predicted orbits for GPS/GLONASS satellites
gfuWWWD.erp	

Table 2: Recent Processing changes

Date	IGS	IGR/IGU	Change
2012–08–19	w1702	–	Switch from 7–day to 1–day SINEX files
2013–05–05	w1739	–	Generation of 30–sec clock products (Final only)
2013–09–26	w1758	w1759.4	Implementation of albedo and antenna thrust modelling
For the reprocessing campaign following changes were implemented:			
			2^{nd} order ionosphere corrections (only REPRO2)
			VMF (only REPRO2)

Table 3: Number of stations and processing time for different GFZ products

IGS Product	#Sites	#Sites GLONASS	Duration [h]
Ultra	95	65	~ 1
Rapid	110	80	~ 2
Final	200	115	~ 4

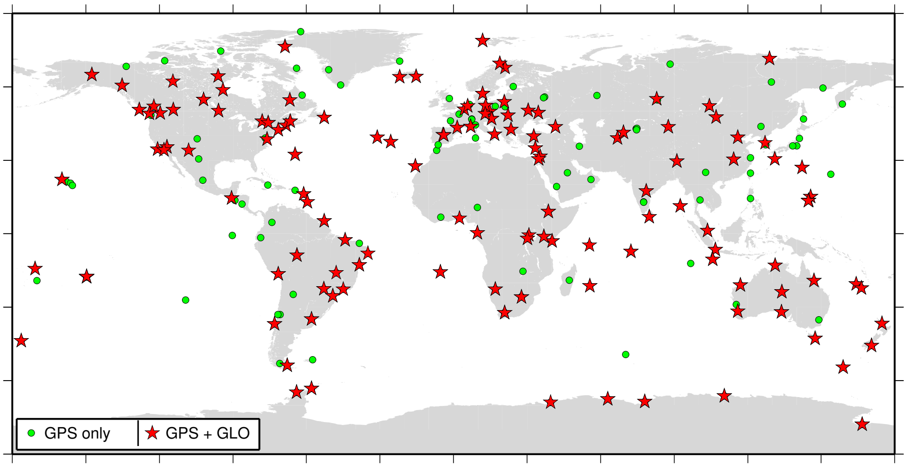


Figure 1: Used IGS stations for combined GPS+GLONASS data processing.

3.1 New 30–sec clock product

Since middle of 2013 GFZ is generating 30–sec clock solutions for the Final network. In a last step, after the 5–min data analysis is finished, the computation of the 30–sec clock corrections is performed. This step is using the cleaned data including all known ambiguities to solve in a single adjustment step all the clock corrections. This step takes about 30 min per day. The final clock product files contain 5–min clocks for all stations, 30–sec clocks for the satellites and in addition 30–sec clocks for a few good stations to be able to switch the reference clock also for the 30–sec clocks.

3.2 Generation of daily SINEX files

Compared to the weekly SINEX files the daily SINEX files can provide better resolution of loading displacements as well as tracking of discontinuity events, etc. At GPS week 1702 GFZ switched to the daily SINEX files for the operational final solution. The daily SINEX files are strictly based on daily data.

3.3 Albedo and antenna thrust modelling

For the albedo modelling the analytical model from Rodriguez–Solano et al. (2012) was implemented. The thruster power is not well documented for all satellites, so the following values are used at the moment:

- Antenna power default is set to 80 Watts for all satellites.
- For GPS satellites the values are defined as follows:

Block I/II/IIA	:	76 Watts
Block IIR–A/B	:	85 Watts
Block IIR–M	:	198 Watts
Block IIF	:	249 Watts (154 Watts if no M–CODE)

The activation of the albedo modelling is resulting in a scale "jump" of the orbits of about +0.05 ppb (Fig. 2).

4 Processing of M–GEX data at GFZ

In 2012 the IGS started the MGEX campaign (Montenbruck 2013) where Multi–GNSS station data from a global ground tracking network are collected and made public to the community in RINEX 3 format (MacLeod 2013). The stations receive the data from the new GNSS systems, such as Galileo, BeiDou, and QZSS. About 80 MGEX tracking stations are available to the project in late 2013. Based on these MGEX data GFZ provides precise satellite orbit and clock solutions from a combined processing of GPS+Galileo or GPS+BeiDou observation data.

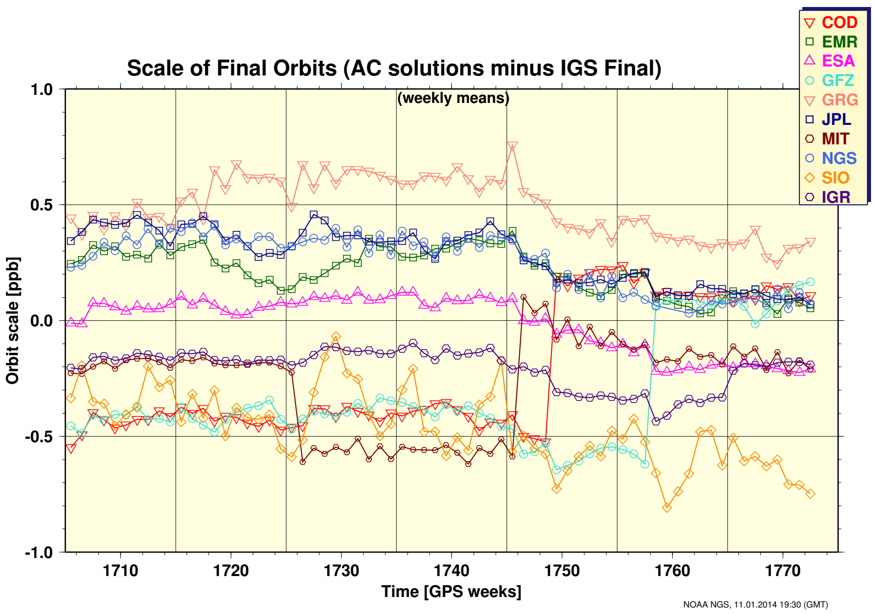


Figure 2: Scale changes in GFZ Final orbits due to the introduction of albedo modelling in week 1759 (plot from ACC web site).

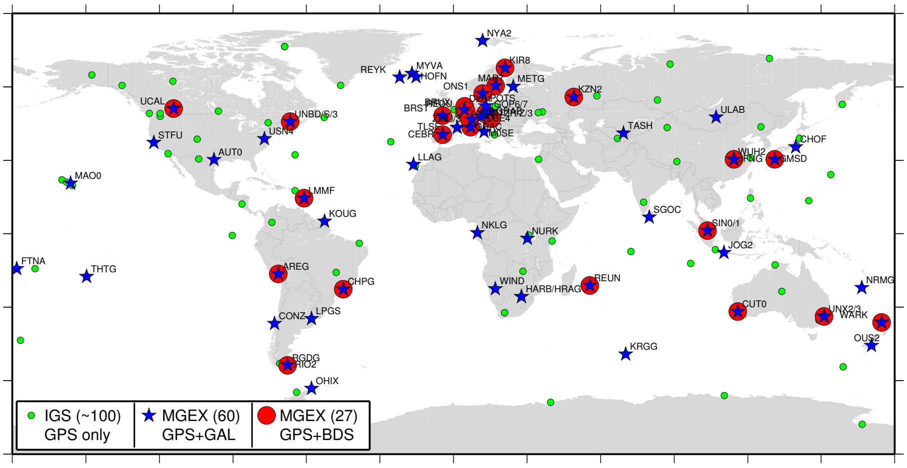


Figure 3: Global network of IGS (green) and MGEX stations, which were set up for data processing. The 60 Galileo–MGEX stations (blue) realize a good global coverage for practical Galileo orbit determination purposes, whereas a lot of the 27 BeiDou–MGEX stations (red) are concentrated in Europe.

4.1 Galileo data processing

The study of Uhlemann et al. (2013) is a demonstration of what is possible with the current MGEX tracking network. The focus lies on precise orbit and clock determination of the four Galileo In–Orbit–Validation (IOV) satellites and also the investigation of station tracking behaviour and orbit issues for a test period of 10 weeks.

It was shown that the Galileo orbits can be determined with accuracies of 5 to 10 cm, which was additionally underlined through comparisons with external solutions of other MGEX–ACs (see Fig. 4) and Satellite Laser Ranging (SLR) observations. The investigations have clearly shown that the contribution of SLR measurements was very useful to identify the source of the periodic variations in the clock estimates. The adjusted satellite clocks and their stabilities are in a level of about 20ps and suffer only from obvious orbit modelling problems during eclipsing periods.

A further enhancement of EPOS–8 was the introduction of Galileo ambiguity fixing. The integer carrier–phase ambiguities are fixed for GPS and Galileo separately. Baseline lengths up to 4000 km were allowed in both cases. To resolve the double–difference ambiguities for Galileo the available stations were grouped according their (receiver–dependent) observation types:

- Group 1: L1C/L5Q (e.g. BRUX)
- Group 2: L1X/L5X (e.g. POTS)

Only between stations belonging to the same group it was in a first step allowed to select

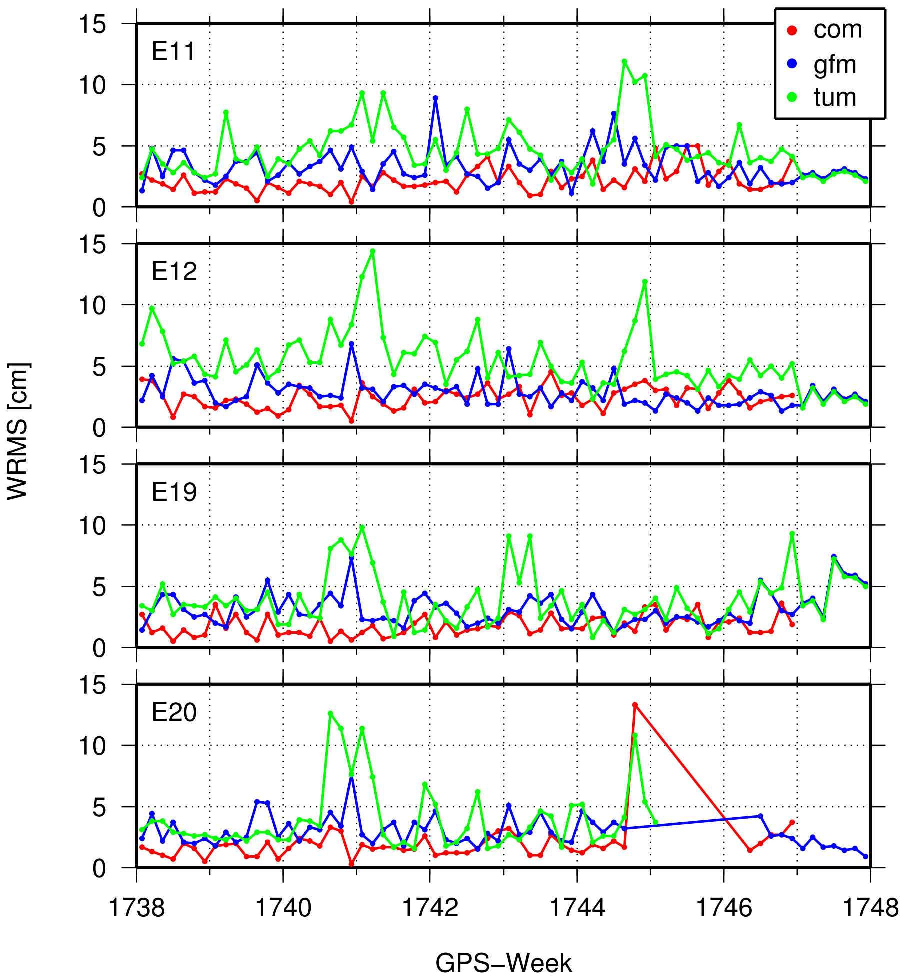


Figure 4: Weighted RMS (WRMS) of individual MGEX–AC orbits with respect to the combined result for all Galileo–IOV satellites (Note: E20 out–of–service around GPS–week 1745)

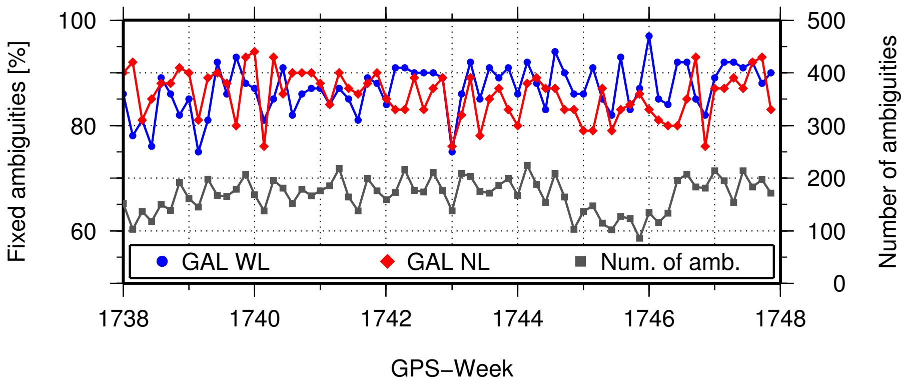


Figure 5: Galileo ambiguity fixing success rates for wide–lane (blue) and corresponding narrow–lane (red) ambiguities as well as the total number of ambiguities (black).

the linear independent baselines until afterwards all remaining baselines were defined. The statistic of the Galileo wide–lane (WL) and narrow–lane (NL) ambiguities is given in Fig. 5. It can be seen that, despite their low overall number, it is possible to fix the Galileo ambiguities with a success rate of only about 85%. This may be a result from the very long baseline lengths, because only max. 30% of the baselines are shorter then 1000 km, or it may come from the different observation types which are given in the network. These effects will be studied further.

4.2 BeiDou data processing

Currently the Chinese BeiDou constellation provides observation data of five Geostationary–Earth–Orbit (GEO) satellites, five Inclined–GeoSynchronous–Orbit (IGSO) satellites and four Medium–Earth–Orbit (MEO) satellites.

Based on tracking data of BeiDou–capable receivers from the MGEX network up to 27 global distributed stations (red circles in Fig. 3) are selected to estimate orbit and clock parameters of the BeiDou satellites. The orbit analysis is based on a time period of 2 weeks, namely GPS–weeks 1753 and 1759.

4.2.1 Processing Scheme

An upgraded version of EPOS.P8 software is used for the processing of dual–frequency GPS+BeiDou data. The general processing strategy is similar to the GPS+Galileo processing scheme, ambiguity–fixing was also set up for BeiDou IGSO and MEO satellites. The ionosphere–free linear combination of B1 (1561.098 MHz) and B2 (1207.140 MHz) is used and the a priori orbits are taken from the broadcast navigation message files, which are provided by MGEX. The observation data are processed in daily batches and normal

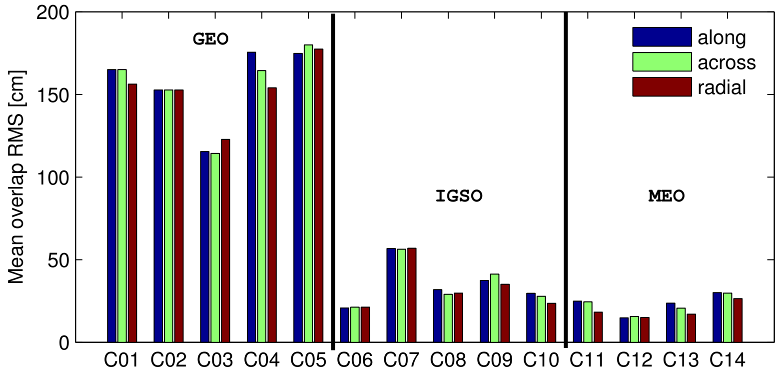


Figure 6: Mean orbit overlap RMS[cm] in along, across and radial.

equations (NEQs) are kept to generate 3–day solutions.

4.2.2 Results

To check the orbit quality the RMS of the orbit overlap differences (4 hours) in along–track, cross–track and radial directions are taken. The statistic results are given in Fig. 6. GEOs have a larger RMS than IGSOs and MEOs, because the GEO orbit determination suffers clearly from the weak observation geometry and the lack of orbit dynamics which result higher RMS values. The individual results of the four MEOs are more homogeneous than the others which are related to our orbit modelling experiences for this kind of satellites.

5 Reprocessing activities

GFZ is contributing to the IGS and TIGA Reprocessing Campaign. For the IGS/TIGA reprocessing the GPS data of the global tracking network of 307/794 stations for the time span from begin of 1994 until end of 2012 (GPS weeks 730 to 1720) were reprocessed. The numbers of reprocessed GPS satellites/stations are given in Fig. 7 and the distribution of the GPS stations is shown in Fig. 8. The reprocessing is performed on the local Linux cluster with a maximum number of 40 computers/servers. With EPOS.P8 a high degree of automation of the individual processing jobs can be achieved.

Since the processed number of TIGA stations can reach up to 560 daily (Fig. 7) and EPOS.P8 can process up to 250 stations in a single job, the TIGA stations must be split into several sub–networks. One of the sub–networks is the IGS reprocessing network, which has been done with a processing scheme similar to GFZ IGS routine analysis. A flow diagram of the TIGA reprocessing is shown in Fig. 9.

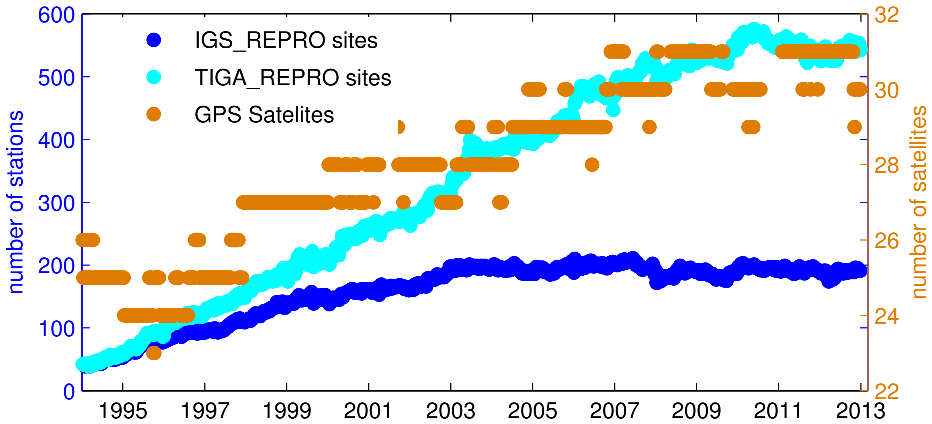


Figure 7: Weekly number of stations and satellites included in the IGS/TIGA reprocessing. TIGA reprocessing is based on the same set of IGS stations, so that the difference to IGS reprocessing shows the number of processed TIGA–only stations.

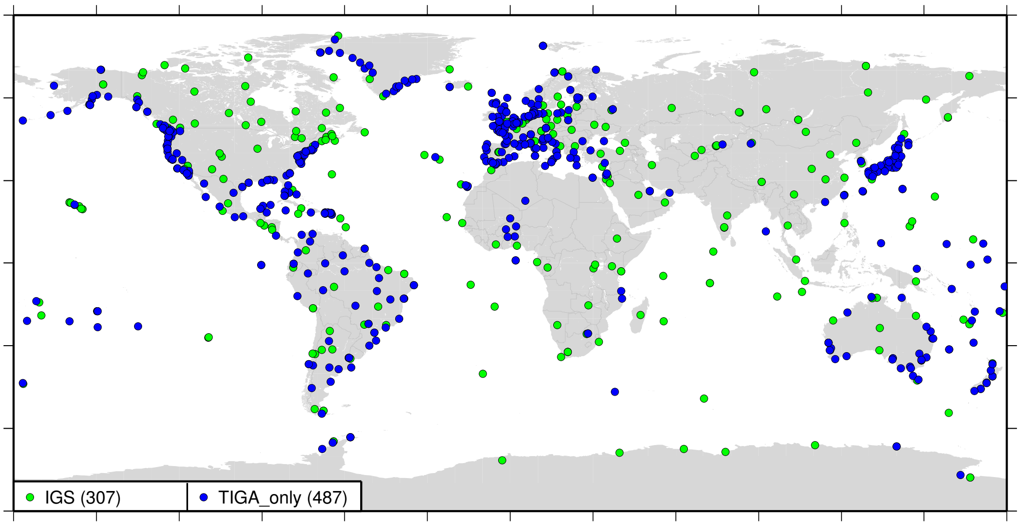


Figure 8: Global distribution of the reprocessed GPS stations for IGS and TIGA–only.

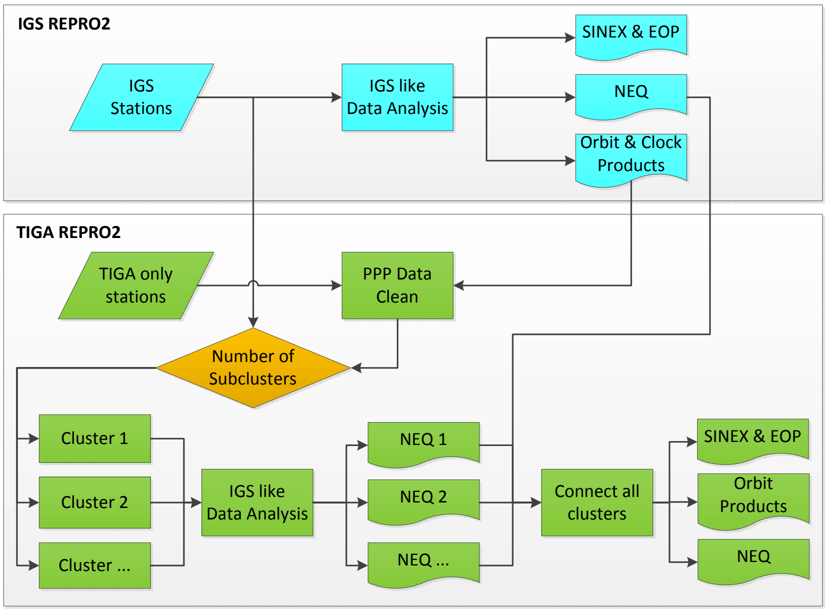
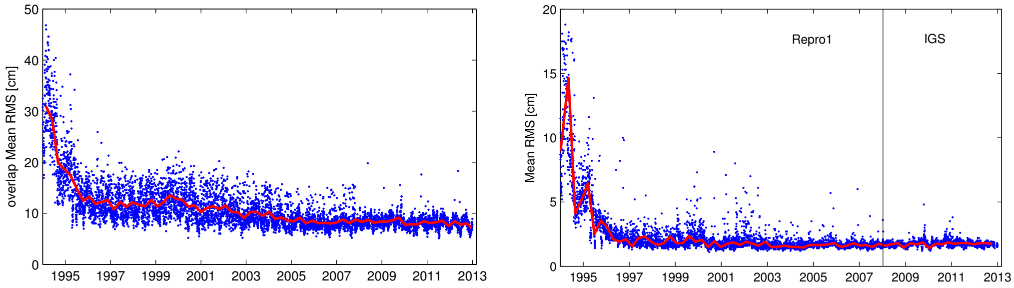


Figure 9: The IGS reprocessing scheme is similar to GFZ routine IGS analysis processing scheme. Its orbit and clock products are introduced and fixed for TIGA reprocessing to clean the data. The final TIGA solution is the result of a NEQ stacking (clusters + IGS reprocessing).



(a) (b)

Figure 10: Mean RMS values of IGS processing orbit overlaps (4 hours) [left] and of transformed GFZ IGS reprocessing orbits w.r.t. the reprocessing (1994.0–2008.0) and the IGS Final orbits (2008.0–2013.0) [right]. The solid line represents a 100–day median.

The TIGA data reprocessing is done in two steps, first precise satellite clocks, orbits and 1–day normal equations are generated from the IGS REPRO2 using the IGS stations. In the second step the TIGA stations, which are not already included in IGS REPRO2, named TIGA–only stations, are processed. The IGS REPRO2 satellite clock and orbit products are introduced and fixed to clean the observation data in PPP mode.

Because of the large number of the TIGA–only stations up to 2 sub–networks are build and processed in network mode. The final TIGA solution is the result of a Normal Equation (NEQ) stacking of all sub–networks. For connecting the sub–networks 30 globally distributed IGS REPRO2 stations are selected and processed together with the TIGA–only sub–networks. The 30 connecting stations are different for each sub–network and are selected automatically from the IGS REPRO2 stations for each day according to its distribution and post fit. If the number of TIGA REPRO2 stations is smaller than 250, the TIGA–only stations will be processed with the IGS REPRO2 stations together as TIGA final solution, and no sub–network is needed.

To quantify the internal consistency of the GPS satellite orbits, the overlap of 2 consecutive 1–day orbit arcs was checked. The daily mean RMS of the overlaps serve as quality indicator, and are shown in Fig. 10(a) [left]. In the first year the RMS is on a level of 15-−50 cmand falls below 10 cmin 2012.

Since the Repro2 combination solutions are not available, the GFZ Repro2 orbits are compared to Repro1 orbits (ig1 1994.0 – 2008.0) and the IGS Final orbits (igs 2008.0 – 2013.0) by 7–parameter similarity transformations. The mean RMS of the transformed reprocessed orbits w.r.t. the ig1/igs orbits is shown in Fig. 10(b) [right]. The RMS decreases rapidly from about 15 cm in 1994 to about 2 cm in the mid of 1995.

6 Meta Data Management with SEMISYS

The precise analysis of GNSS observation data is based upon a variety of metadata from different sources, including station and satellite metadata. A high evaluation quality must be ensured by the consistency and integrity of these meta information.

The station and satellite meta information are currently maintained in ASCII based files, that makes the extraction of key information used for the data evaluation difficult. To get rid of the restrictions caused by the file based metadata management, the Operational Data Center (ODC) group of the GFZ developed a Sensor Meta Information System (SEMISYS) for the centralized, format independent and validated storage of station and satellite metadata based upon a relational database.

The system is used for the handling of approximately 1600 stations analysed in different projects (e.g. IGS, MGEX, TIGA, etc.) at GFZ. It contains the following meta information:

- Station meta information extracted from IGS site logs,
- Hardware meta information (receiver, antenna, radome) extracted from the IGS rcvr_ant.tab, and IGS antenna.gra
- Satellite parameter for the GNSS systems GPS, GLONASS, Galileo, BeiDou, QZSS and SBAS extracted from different sources (ANTEX, formats and specifications of the satellite manufacturers).
- Notice advisories from GPS, GLONASS, and Galileo (NANU,NAGU)

Our approach leads to the following advantages:

1. Centralized, easy and fast on–demand access to all meta information concerning the IGS station network,
2. Easy build–up of connections between metadata (finding similarities, differences or specific information),
3. Easy maintenance of station meta information based on a web editor (no files necessary anymore),
4. Validation of all (and not only mandatory) site log entries(no confusion about formatting and units etc.),
5. Easy evaluation and exchange of the database generated site logs for all Analysis Centres (AC's),
6. Project across storage of station metadata(no invalid, inconsistent site logs of one and the same station across different projects).

All necessary information can be accessed via web or command line and can thus be ideally used for automated processing tasks.

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GOP Analysis Center Report 2012–2013

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1 Introduction

The Geodetic Observatory Pecny (GOP) Analysis Centre (AC) of the Research Institute of Geodesy, Topography and Cartography (RIGTC) has contributed to the International GNSS Service (IGS) since 2004 with a regular determination of the precise GPS ultra–rapid products.

This technical report addresses two domains. First, the status of the core GOP AC contribution to the IGS. Second, other activities related to the IGS working groups.

2 Contributions to the ultra–rapid products

The ultra–rapid orbits are determined using a highly efficient strategy of the 6-hour raw data pre-processing followed by a consecutive normal equation stacking based on the modified *Bernese GNSS Software* Version 5.0 (Dach et al. 2007). Unfortunately, our original plan in 2013 to replace the software with the up–to–date release Ver. 5.2 was not accomplished due to the lack of the manpower and an overall financial situation at the GOP/RIGTC. Actually, most of this work was postponed for the next year. In spite of the said problems, we were able to provide sufficient support to operate smoothly our official contribution to the IGS over the whole period 2012–2013. A few problems occurred only due to the data unavailability or due to internal IT problems, such as the processing server hardware failure during the GPS week 1767. From the above reasons there were no changes in the strategy or the network used in the GOP regular ultra–rapid product determination. The modifications thus consisted in regular updates of the satellites' and receivers' antenna phase centre offset and variation model (IGS08_week.ATX) only.

The original GOP orbit end Earth rotation parameter products are available via the GOP local data centre too:

- ftp://ftp.pecny.cz/LDC/prod_GOP/GLOBAL/ORB/WWWW/gogWWWWD_HR.erp.Z
- ftp://ftp.pecny.cz/LDC/prod_GOP/GLOBAL/ORB/WWWW/gogWWWWD_HR.sp3.Z

2.1 Experimental GLONASS ultra–rapid orbits and their exploitation

In parallel to the GOP contribution to the official IGS ultra–rapid GPS orbits, the second GOP solution contributed to the IGS experimental GPS+GLONASS ultra–rapid orbits operationally during the period of GPS weeks 1602–1712. This production was interrupted in GPS week 1712 due to the repetitive problems with the GLONASS broadcast ephemeris. We used the TEQC tool (Estey and Meertens 1999) for merging individual GPS and GLONASS ephemeris RINEXN files in the GOP data centre. A long unavailability of the software update fixing this specific problem generated too many manual interventions which, in general, was the main reason to stop this parallel solution. Unfortunately, due to the lack of the manpower we haven't yet started this experimental solution and we decided to postpone it until, first, we finalize the development of our own RINEX quality checking tool for the multi-GNSS observations and navigation messages (G–Nut/Anubis, see below) and, second, we update the *Bernese GNSS Software* to Version 5.2 (together with merging our internal modifications from the previous version and adapting our complex system of the processing for new formats and software functionalities).

Besides the generation of the GLONASS predicted orbits, GOP has regularly exploited both IGS official (GPS) and unofficial (GPS+GLONASS) ultra–rapid products for near real–time zenith tropospheric path delay estimations since June 2001 and May 2011, respectively. Based on the long-term experience with the unofficial product we can state that since the beginning it has provided stable and reliable quality for our operational solution of sensing the troposphere in near real–time (Dousa and Vaclavovic 2013). Additionally, our results showed that the tropospheric parameters estimated using GPS and GPS+GLONASS are of a comparable quality, while the latter even slightly better most likely because of improved multi-GNSS geometry.

2.2 Quality monitoring for the orbit predictions

Since 2009, the IGS ultra–rapid orbits have been routinely monitored at GOP (available at the web: http://www.pecny.cz → GNSS → precise orbits). The real–time portion of the IGS ultra–rapid orbit predictions, which usually ranges between 3–10 hours, are compared (with a delay) to the IGS rapid orbits. However, the comparison process is running in real time, thus reading all inputs at epochs when they become available meaning that any delay in the ultra–rapid product is implicitly included in the monitoring results. Additionally, the comparison statistics are separated into hourly prediction intervals and dependency graphs can visualize satellite specific degradations in the orbit prediction. More details on the monitoring were provided in Dousa (2011) and the GOP AC summary in the IGS Technical Reports 2011.

3 IGS related developments and activities

Due to the lack of the institutional financial support, the GOP had to concentrate to the project-related works. The below are brief summaries of tasks we contributed (or we may contribute in future) to individual IGS working groups and which have been supported by national projects.

3.1 G–Nut/Anubis — development of new multi–GNSS monitoring tool

As described previously, with our aim to support a multi–GNSS ultra–rapid product development (at least for GPS, GLONASS and Galileo soon), we needed a flexible tool for the data quality checking for all future GNSS observations. Together with the development of the G–Nut software library (Vaclavovic et al. 2013) for various end-user applications, we could initiate a project that uses part of the library for the above requirements. The first release of the G–Nut/Anubis tool was made available to public in July 2013 (Vaclavovic and Dousa 2013) through the web: `http://www.pecny.cz` → GNSS → software. The current version supports reading RINEX 2.11 and RINEX 3.02 formats and includes functionality such as a) header data monitoring, b) quantitative data monitoring – number of observations, signals, satellites, frequencies/bands, data gaps, small data pieces and others; all with respect to header information and real data content, c) qualitative data monitoring – cycle slip and clock jump detection, code multipath and noise estimation, d) standard point positioning and satellite azimuth/elevation calculation.

The tool supports observations from all GNSS (GPS, GLONASS, Galileo, BeiDou) and their augmentations (SBAS, QZSS). While the quantitative monitoring statistics are provided to all above mentioned constellations, the limits still remain in the support of navigation messages from the Chinese BeiDou system and from the augmentation satellites including relevant algorithms for the observation pre-processing. On the other hand, we have developed a new generic algorithm for the code multipath and noise monitoring for all available constellations, frequencies/bands and signals, details are provided in Vaclavovic and Dousa (2013). The tool has been tested on the data available from the IGS M-GEX and EUREF experimental campaigns. The example plots showing a year history for two stations from the EUREF permanent network is provided in Fig. 1

Figure 1: Pseudorange multipath estimated for all GNSS signals observed at the EUREF station AXPV (top) and BSCN (bottom) during January–November, 2013

Figure 2: Tefnut ZTD comparisons with respect to EUREF final products – biases (left) and standard deviations (right)

3.2 Real–time troposphere products based on IGS Real–Time Service

Since 2012, the GOP has been developing the G–Nut/Tefnut and G–Nut/Geb applications to apply the Precise Point Positioning (Zumberge et al. 1997) for the troposphere monitoring and the positioning, respectively, both in the post–processing and real–time modes. In February 2013, we initiated an experimental real–time GNSS data processing campaign for 18 European and 18 global stations in the preparation of supporting existing or future meteorological applications. The IGS01, IGS02 real–time precise orbit and clock products from the IGS (Caissy et al. 2012) as well as from individual global product from the CNES (Laurichesse 2011) were operationally exploited in this campaign.

The assessment of the real–time zenith path delays, see Fig. 2 and results are in detail discussed in Dousa and Vaclavovic (2014). Together with the monitoring of coordinate residuals in a pseudo–kinematic positioning mode, it revealed that the quality of the individual CNES real–time product is slightly better than the quality of any IGS combined product. This indicates a room for a possible improvement in the combination process.

On the other hand, no overall differences between combined products applying either the epoch-wise combination or the Kalman filtering were observed and thus no general preference on individual product use identified.

3.3 GOP-TropDB – development of troposphere evaluation tool

The GOP-TropDB high-performance databased development was initiated at GOP in 2011 as a tool of the third generation for an intra–/inter–technique tropospheric parameter comparisons. At the IGS workshop in Olsztyn, it was recognized as a suitable instrument for a flexible automated comparison within the IGS Troposphere WG in future. From this time we consult our developments and planned functionalities with the Tropospheric WG Chair, Dr. Christine Hackmann from USNO. The GOP-TropDB implementation and technical aspects were provided in Dousa and Gyori (2013). During 2013, the database was tested with preliminary inclusion of tropospheric products from space geodetic techniques (GNSS, VLBI, DORIS), meteorological observations (radio sounding, water vapour radiometers, in-situ measurements) as well as numerical weather model data fields. A feedback was also provided about specific problems in the IGS final tropospheric product. Finally, a special attention was given to the development of the more accurate tropospheric wet delay ties in order to support as much as precise comparison for collocated station from various observing techniques in particular with significant differences in altitudes. The extension towards new auxiliary data and models (EGM2008, GPT2, etc.), support of data from numerical weather fields, definition of new tropospheric ties, and finally, initial examples already demonstrating basic database functionalities were provided in Gyori and Dousa (2013).

Acknowledgement

The development of the G–Nut/Anubis tool for multi-GNSS observation and navigation data monitoring was partly supported by the project of the Czech Ministry of Eduction, Youth and Science (No. TB01CUZK006). The development of the G–Nut/Tefnut and G–Nut/Geb applications for the real–time troposphere and position estimation and the GOP–TropDB were supported by the Czech Science Foundation (No. P209/12/2207).

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1 Introduction

Our contribution is limited to "final" GPS and GLONASS products. We process zero–difference GNSS observations using the *GINS CNES/GRGS* software (Melachroinos et al. 2011) and the processing strategy described in Loyer et al. (2012). More information on our AC activity can also be found at: `http://www.igsac-cnes.cls.fr`.

Users wishing to use GRG GPS orbit and clock products in order to fix phase ambiguities to integer values in a PPP mode (Laurichesse and Mercier 2007) should apply Wide–Lane Satellite Biases (WSB) to their observations as described in Fund et al. (2013). These WSB are available at: `ftp://ftpsedr.cls.fr/pub/igsac`.

2 GRG products evolution

The major evolution in the routine processing concerns LOD products which were rejected from the combination due to their high noise level. The reason has been identified and was due to a high correlation between this parameter and the empirical accelerations we were estimating (cf. `http://acc.igs.org/orbits/srp-models_cnes_egu11.pdf`). A new SRP model associated to a different parameterization is under development. In the meantime, we decided week 1759, to stop estimating 1/rev term in the sun direction for block–IIA satellites. The LOD solution improvement is clear in Fig. 1 and GRG products are now contributing to the combination.

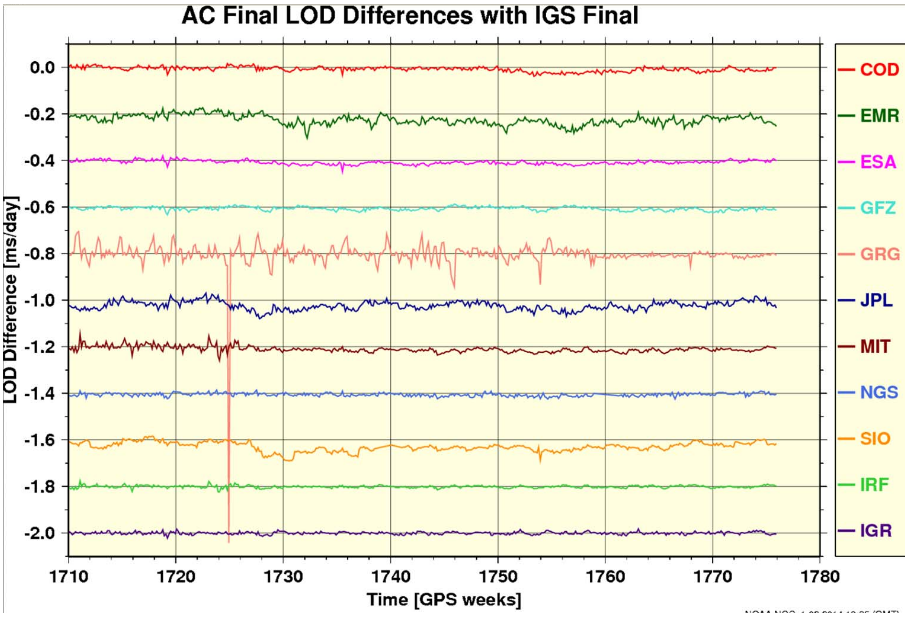

Figure 1: Starting week 1759, GRG LOD series noise is significantly reduced. (Courtesy of J. Griffiths NOAA/NGS `http://acc.igs.org`)

3 Changes to models, standards and processing strategy

Most of the models and standards changes were motivated by the preparation for the REPRO2 reprocessing campaign. The more noticeable points are listed in Tab. 1.

Time Variable Gravity (TVG) field clearly impacts LEO orbit precision (Cerri et al. (2010) & (2013)). The impact on MEO orbits should be small but cannot be neglected mainly through its aliasing with semi–annual and annual geophysical signals (Melachroinos et al. 2013). We choose the EIGEN6–S model (`http://grgs.obs-mip.fr/`

Table 1: Major model evolution

Model	Description
Gravity field	EIGEN6–S including secular rates + annual/ semi–annual terms up to degree 12
Ocean tides	FES2012, gravity field+station loading
Ionospheric correction	Second order from IERS2010 & IGRF2011 (TEC from IGS/IGR–iono grids)
Tropospheric correction	GPT2 for P, T, RH & VMF1 mapping function coefficients
Antenna thrust	Applied for GPS satellites using conventional power transmission values

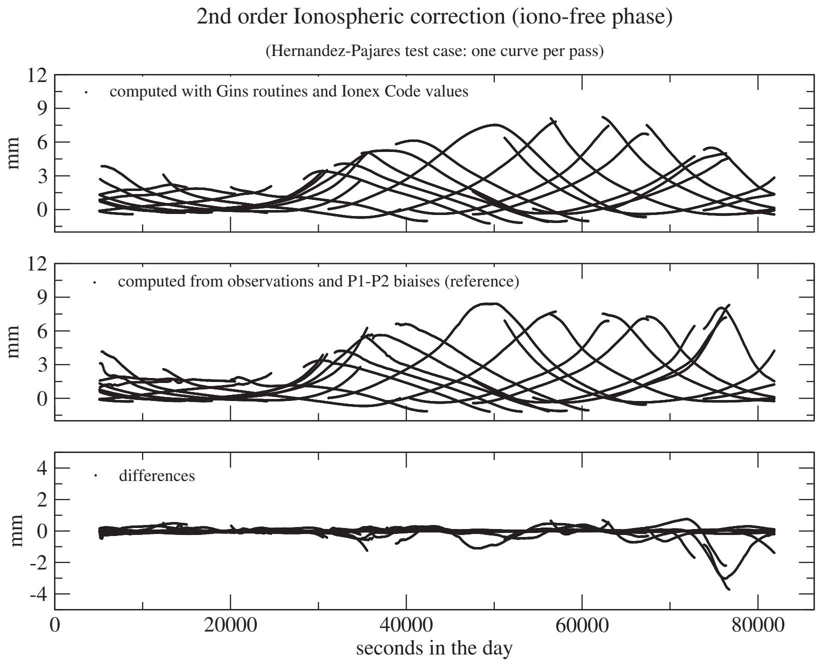

Figure 2: Comparison of second order ionospheric range corrections computed from a reference model with the GINS's implementation.

grace/variable-models-grace-lageos/mean_fields) and associated de–aliasing products as a reference for the REPRO2 campaign. The corresponding ocean loading model for both gravity field and station loading displacement computation is FES2012 (Carrere et al. 2012).

In order to validate the implementation of the second order ionospheric correction, we used the test case provided by Hernández–Pajares et al. (2007). Fig. 2 compares his reference model to the GINS's approach based on IONEX maps. The difference between the two (down plot) is below the millimeter level.

Antenna thrusts are taken into account for GPS satellites only as no published values exist for GLONASS and Galileo. Two orbit solutions with and without considering this effect are compared in Fig. 3. The main impact is a negative bias of the satellite radial components of around 4 mm for blocks IIA/IIR and of around 8 mm for blocks IIR–M and II–F.

In the framework of our investigations on solar radiation pressure models, we have implemented the capability to use the sub–solar point for the phase origin of the computation of sinusoidal empirical accelerations.

Last but not least, the entire processing chain has been moved to a new CNES computing

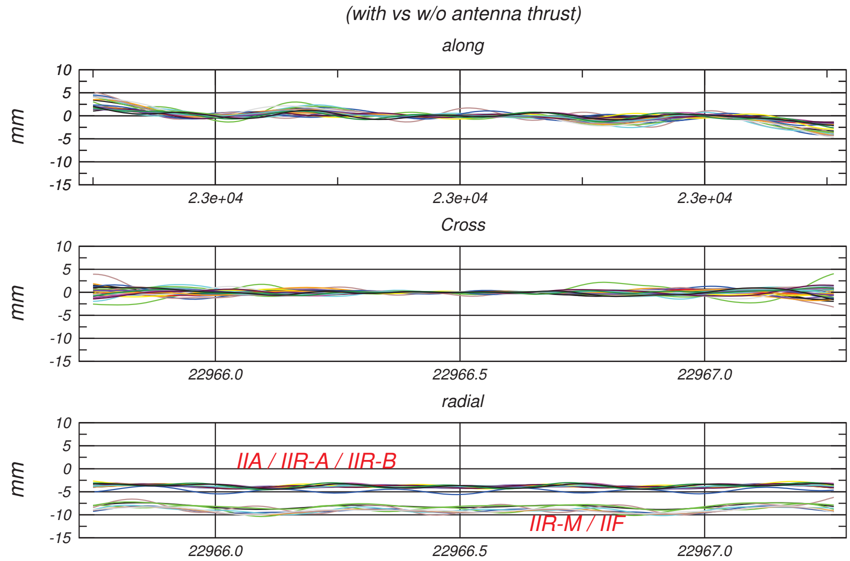

Figure 3: Along–track, Cross–track and Radial orbit comparison with and without taking into account antenna thrust.

facility based on a 1168 core LINUX cluster.

4 IGS M–GEX campaign data analysis

Our contribution to the IGS M–GEX experiment focuses on the Galileo satellites orbit and clock computation as well as on the Galileo signals biases determination. Data from a global network of more than 50 stations are processed on a routine basis. GRG Galileo orbit and clock products (called "GRM") are available at: ftp://cddis.gsfc.nasa.gov/pub/gps/products/mgex.

Future Galileo satellites and ground tracking stations data will be included in the processing as soon as will become available.

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JPL IGS Analysis Center Report 2013

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1 Introduction

In 2013, the Jet Propulsion Laboratory (JPL) continued to serve as an Analysis Center (AC) for the International GNSS Service (IGS). We contributed orbit and clock solutions for the GPS satellites, position, clock and troposphere solutions for the ground stations used to determine the satellite orbit and clock states, and estimates of Earth rotation parameters (length–of–day, polar motion, and polar motion rates). This report summarizes the activities at the JPL IGS AC in 2013 and our preparations for the 2014 IGS reprocessing campaign.

Tab. 1 summarizes our contributions to the IGS Rapid and Final products. All of our con-

Table 1: JPL AC Contributions to IGS Rapid and Final Products.

Product	Description	Rapid/Final
jplWWWWd.sp3	GPS orbits and clocks	Rapid & Final
jplWWWWd.clk	GPS and station clocks	Rapid & Final
jplWWWWd.tro	Tropospheric estimates	Rapid & Final
jplWWWWd.erp	Earth rotation parameters	Rapid(d=0–6), Final(d=7)
jplWWWWd.yaw	GPS yaw rate estimates	Rapid & Final
jplWWWWd.snx	Daily SINEX file	Final
jplWWWW7.sum	Weekly solution summary	Final

tributions are based upon daily solutions centered at noon and spanning 30–hours. Each of our daily solutions is determined independently from neighboring solutions, namely without applying any constraints between solutions. We have been delivering daily SINEX files starting with GPS week 1702.

The JPL IGS AC also generates Ultra–Rapid orbit and clock products for the GPS constellation (Weiss et al. 2010). These products are generated with a latency of less than 2 hours and are updated hourly. Although not submitted to the IGS, our Ultra–Rapid products are available in native *GIPSY* formats at:
ftp://sideshow.jpl.nasa.gov/pub/JPL_GPS_Products/Ultra.

2 Processing Software and Standards

The JPL AC continues to utilize the *GIPSY/OASIS* software package to generate our contributions to the IGS. Starting GPS week 1738 (April 28, 2013), we used *GIPSY/OASIS* version 6.2 to generate our IGS contributions. A complete description of our current processing approach can be found at: http://igscb.jpl.nasa.gov/igscb/center/analysis/jpl.acn. Of note, we continue to use empirical GPS solar radiation pressure models developed at JPL instead of the DYB–based strategies that are commonly used by other IGS analysis centers. This choice is based upon an extensive evaluation of various internal and external metrics after testing both approaches with the *GIPSY/OASIS* software (Sibthorpe et al. 2011).

3 Preparations for 2014 IGS Reprocessing Campaigns

In November 2012 we completed a preliminary reanalysis of historical GPS data from August 16, 1992 to present in the IGS08 reference frame, and made these products publically available (Desai et al. 2011). They are available at:

- ftp://sideshow.jpl.nasa.gov/pub/jpligsac in IGS formats, and
- ftp://sideshow.jpl.nasa.gov/pub/JPL_GPS_Products/Final in *GIPSY* formats.

A notable benefit of these preliminary reprocessed IGS08–products is that they include our so–called "wide–lane phase bias" (WLPB) file for the entire time span of the products. The WLPB files enable single–receiver phase ambiguity resolved positioning when used with the *GIPSY/OASIS* software (Bertiger et al. 2010) and our GPS orbit and clock products. Also of note, high–rate (30–second) GPS clock products in native *GIPSY* format were also generated in this preliminary reanalysis for the period May 5, 2000 to present. They are also generated operationally in native *GIPSY* format for our Rapid and Final solutions.

Our contributions to the 2014 reprocessing campaign are expected to benefit from the results and experience gained from our preliminary analysis. Over the course of 2013 we tested various modifications to our processing standards that we will implement for the 2014 reprocessing campaign, as well as operations. These modifications include:

- Application of second order ionospheric corrections (Garcia–Fernandez et al. 2013).
- Revised empirical solar radiation pressure model named GSPM13, following Sibthorpe et al. (2010).
- Antenna thrust models per IGS recommendations.
- Modern ocean tide loading, using GOT4.8 (Ray 2013) (appendix) instead of FES2004 (Lyard et al. 2006).
- GPT2 troposphere models and mapping functions (Lagler et al. 2013).
- Elevation–dependent data weighting.

We will deliver the full suite of products listed in Tab. 1 to the 2014 IGS reprocessing campaign, and also include high–rate (30–second) GPS clock products for May 5, 2000 onwards. We also plan to include high–rate (30–second) GPS clock products in our operational deliveries to the IGS when our new processing standards become operational.

4 Future Activities

Our primary focus in 2014 is to support the second IGS reprocessing campaign and existing operations.

5 Acknowledgments

The work described in this report was performed at the Jet Propulsion Laboratory, California Institute of Technology under a contract with the National Aeronautics and Space Administration.

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United States Naval Observatory (USNO) Analysis Center Report 2013

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1 Introduction

The United States Naval Observatory (USNO), located in Washington, DC, USA has served as an IGS Analysis Center (AC) since 1997, contributing to the IGS Rapid and Ultra–rapid Combinations since 1997 and 2000, respectively. USNO contributes a full suite of rapid products (orbit and clock estimates for the GPS satellites, earth rotation parameters (ERPs), and receiver clock estimates) once per day to the IGS by the 1600 UTC deadline, and contributes the full suite of ultra–rapid products (post–processed and predicted orbit/clock estimates for the GPS satellites; ERPs) four times per day by the pertinent IGS deadlines.

USNO has also coordinated IGS troposphere activities since 2011, producing the IGS Final Troposphere Estimates and chairing the IGS Troposphere Working Group (IGS TWG).

The USNO AC is hosted in the GPS Analysis Division (GPSAD) of the USNO Earth Orientation Department (EOD). Dr. Christine Hackman, GPSAD chief, directs AC activities, chairs the IGS TWG, and serves on the IGS Governing Board. Dr. Sharyl Byram oversees production of the IGS Final Troposphere Estimates. All GPSAD members, including Dr. Victor Slabinski, Mr. Jeffrey Tracey and contractor Mr. James R. Rohde, participate in AC work.

USNO AC products are computed using *Bernese GPS Software* (Dach et al. 2007)[1]. Rapid products are generated using a combination of network solutions and precise point posi-

[1]Prior to 2009, the rapid products were computed using Jet Propulsion Laboratory (JPL) *GPS Inferred Positioning System* (*GIPSY*) (Webb and Zumberge 1997).

tioning (PPP; Zumberge et al. (1997)). Ultra–rapid products are generated using network solutions. IGS Final Troposphere Estimates are generated using PPP.

GPSAD also generates a UT1–UTC–like value, *UTGPS*, five times per day. *UTGPS* is a GPS–based extrapolator of VLBI–based UT1–UTC measurements. The IERS[2] Rapid Combination/Prediction Service uses UTGPS to improve post–processed and predicted estimates of UT1–UTC. Mr. Tracey oversees *UTGPS*.

USNO rapid, ultra–rapid and UTGPS products can be downloaded immediately after computation from `http://www.usno.navy.mil/USNO/earth-orientation/gps-products`. IGS Final Troposphere Estimates can be downloaded at `ftp://cddis.gsfc.nasa.gov/gps/products/troposphere/zpd`.

2 Developments and Product Performance in 2013

The precision of USNO ultra–rapid products improved markedly in 2013 due to (a) lengthening of the data–observation window used for orbit/clock prediction from 27 hours to 40 hours and (b) strengthening of the geodetic ties to the IGb08 reference frame. Item (b) processing changes were implemented in USNO rapid processing as appropriate, improving several of the rapid products as well.

Figs. 1–4 show the 2013 performance of USNO rapid and ultra–rapid GPS products, with summary statistics given in Tab. 1. USNO rapid orbits had a median weighted RMS (WRMS) of 16 mm with respect to the IGS rapid combined orbits. The USNO ultra–rapid orbits had median WRMSs of 17 mm (24–h post–processed segment) and 37 mm (6–h predict) with respect to the IGS rapid combined orbits, reductions of 23–24% compared to the 2012 22/49 mm past/predict median WRMS differences.

USNO rapid (post–processed) and ultra–rapid 6–h predicted clocks had median 146 ps and 1902 ps RMSs with respect to IGS combined rapid clocks, with the median RMS of the ultra–rapid clocks reduced 35% from the 2012 value of 2929 ps.

USNO rapid polar motion estimates had (x, y) 130 and 99 micro arc sec RMS differences with respect to IGS rapid combined values. These RMS differences were 22% and 49% improved over the 2012 (166, 195) RMS difference values. USNO ultra–rapid polar motion estimates differed (RMS; x, y) from IGS rapid combined values by 79 and 116 micro arc sec for the 24–h post–processed segment, 55% and 49% improved over the 2012 (175, 226) RMS–difference values. The USNO ultra–rapid 24–h predict–segment values differed (RMS; x, y) from the IGS rapid combined values by 336 and 277 micro arc sec, 5% and 13% improved over the 2012 (355, 319) values.

The USNO AC began incorporating measurements from the Russian GLONASS GNSS into processing in 2011 Byram and Hackman (2012a) and (2012b) and has been com-

[2] International Earth Rotation and Reference Systems Service

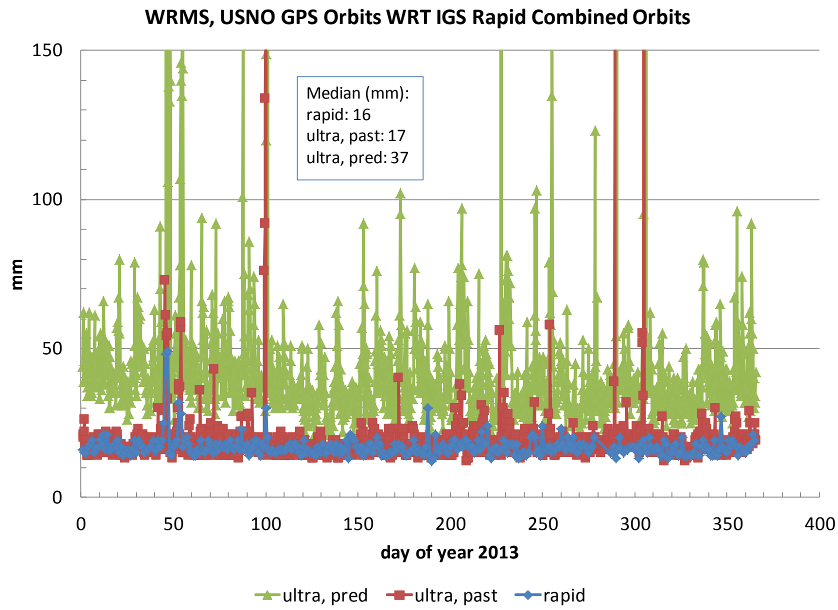

Figure 1: Weighted RMS of USNO GPS orbit estimates with respect to IGS Rapid Combination, 2013. "Ultra, past" refers to 24–hour post–processed section of USNO ultra–rapid orbits. "Ultra, pred" refers to first six hours of ultra–rapid orbit prediction.

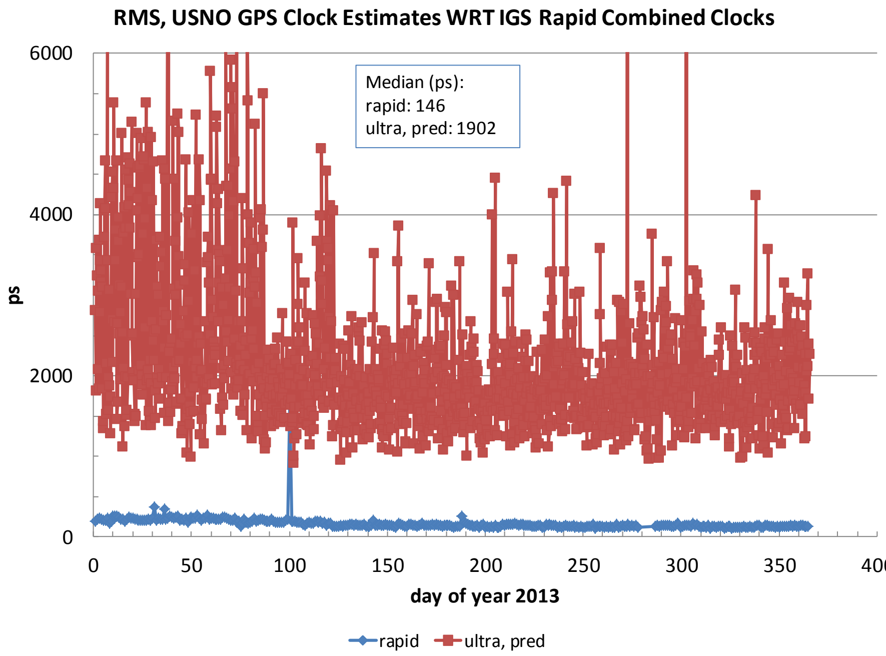

Figure 2: RMS of USNO GPS rapid clock estimates and ultra–rapid clock predictions with respect to IGS Rapid Combination, 2013.

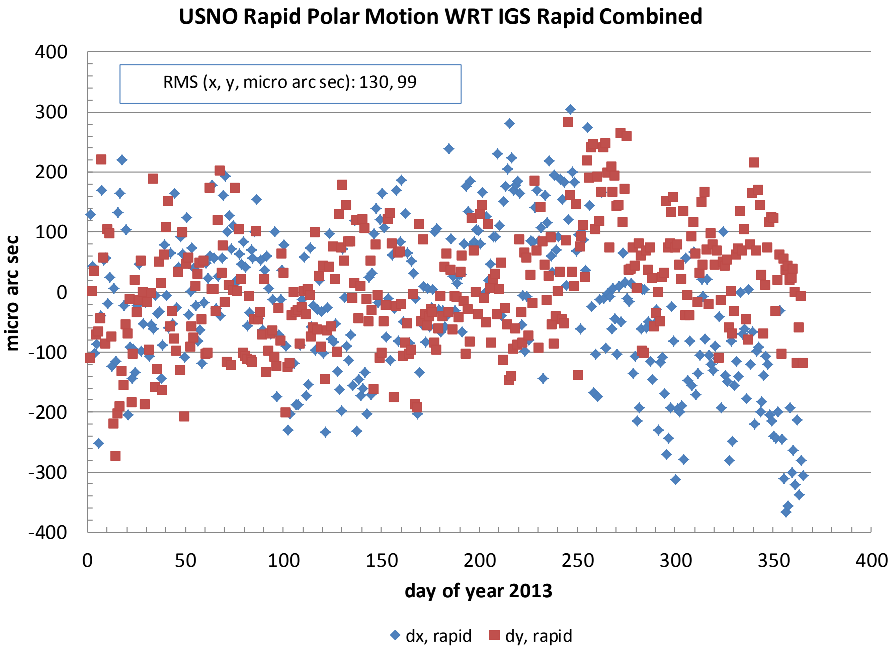

Figure 3: USNO rapid polar motion estimates minus IGS Rapid Combination values, 2013.

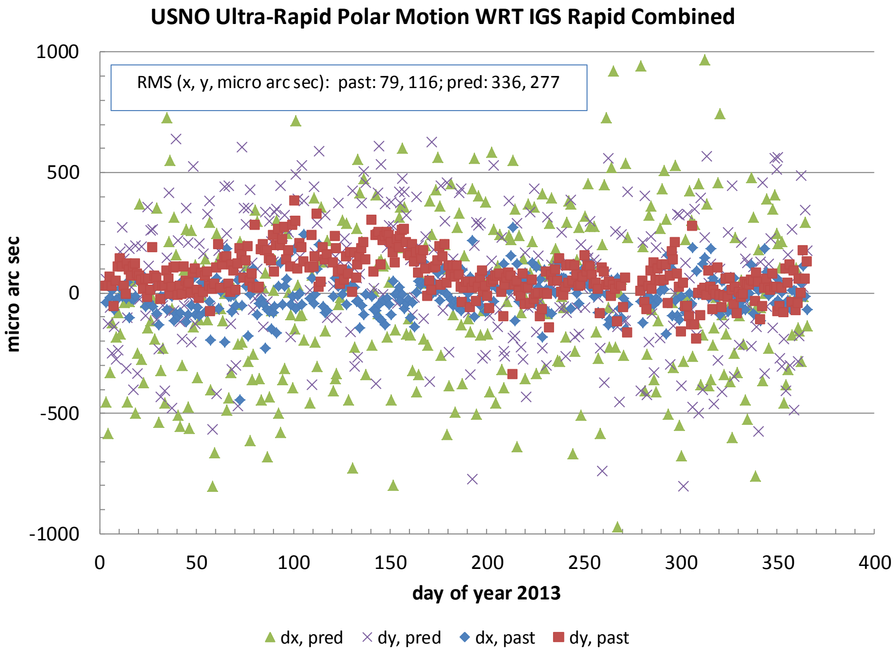

Figure 4: USNO ultra–rapid polar motion estimates minus IGS Rapid Combination values, 2013.

Table 1: Precision of USNO Rapid and Ultra–Rapid Products: 1 Jan. – 31 Dec. 2013. All statistics computed with respect to IGS Combined Rapid Products

	USNO GPS satellite orbits			**USNO GPS–based polar motion estimates**			**USNO GPS–based clock estimates**	
	Statistic: median weighted RMS difference units: mm			Statistic: RMS difference units: 10^{-6} arc sec			Statistic: median RMS difference units: ps	
dates	rapid	ultra–rapid		rapid	ultra–rapid		rapid	ultra–rapid
		past 24h	6h predict		past 24h	24h predict	past 24h	6h predict
1/1/2013 – 12/31/2013	16	17	37	x: 130 y: 99	x: 79 y: 116	x: 336 y: 277	146	1902

Table 2: Precision of USNO Ultra–Rapid GPS+GLONASS Test Products: 1 Jan – 31 Dec 2013. Orbit statistics computed with respect to IGV Combined Ultra–Rapid GPS+GLONASS Products. Polar motion statistics computed with respect to past–24–hr segment of IGU GPS–only values

	USNO GLONASS satellite orbits		**USNO GPS+GLONASS polar motion estimates**
	Median RMS of 7–parameter Helmert transformation units: mm		RMS difference units: 10^{-6} arc sec
dates	past 24h	6h predict	past 24h
6/27/2013 – 12/31/2013	50	117	x: 105, y: 69

puting a full set of test rapid and ultra–rapid combined GPS+GLONASS products since 2012. These estimates are not yet submitted to the IGS. In the second half of 2013, seven–parameter Helmert transformations computed between USNO and IGS ultra–rapid GLONASS orbits had median RMSs of 50 and 117 mm for the 24–h post–processed and 6–h predict portions, respectively. Meanwhile, the USNO GPS+GLONASS ultra–rapid 24–h post–processed polar motion values differed from the 24–hr post–processed segment of the IGS ultra–rapid GPS–only (aka IGU) values, RMS, by 105 and 69 micro arc sec, respectively. These data are shown in Tab. 2/Figs.5–6.

The USNO AC acquired *Bernese GNSS Software* Ver. 5.2 in 2013 and plans to release official AC products generated using it in 2014.

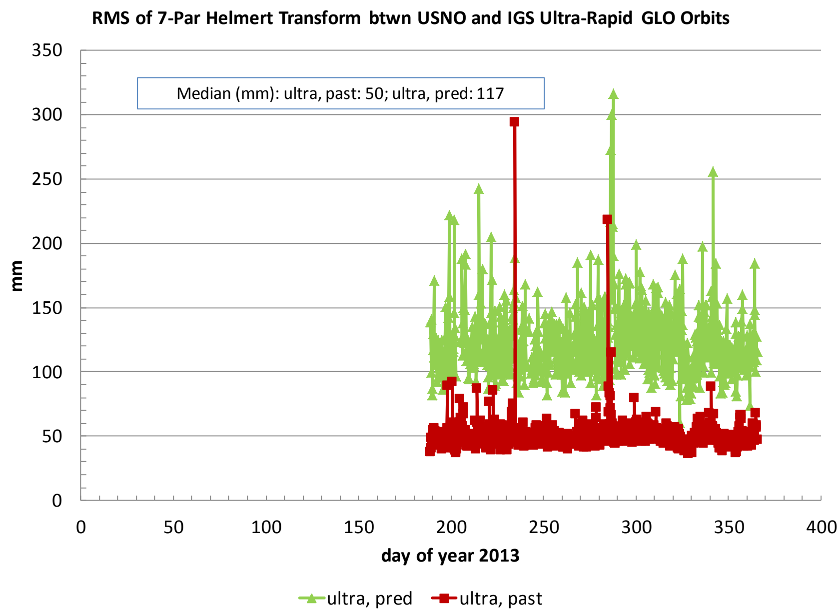

Figure 5: RMS of USNO ultra–rapid GLONASS orbit estimates with respect to IGS Combined Ultra–rapid GLONASS orbits, 2013. "Ultra, past" refers to 24–hour post–processed section of USNO ultra–rapid orbits. "Ultra, pred" refers to first six hours of ultra–rapid orbit prediction. Helmert transformations computed using *Bernese GPS Software* Ver. 5.0.

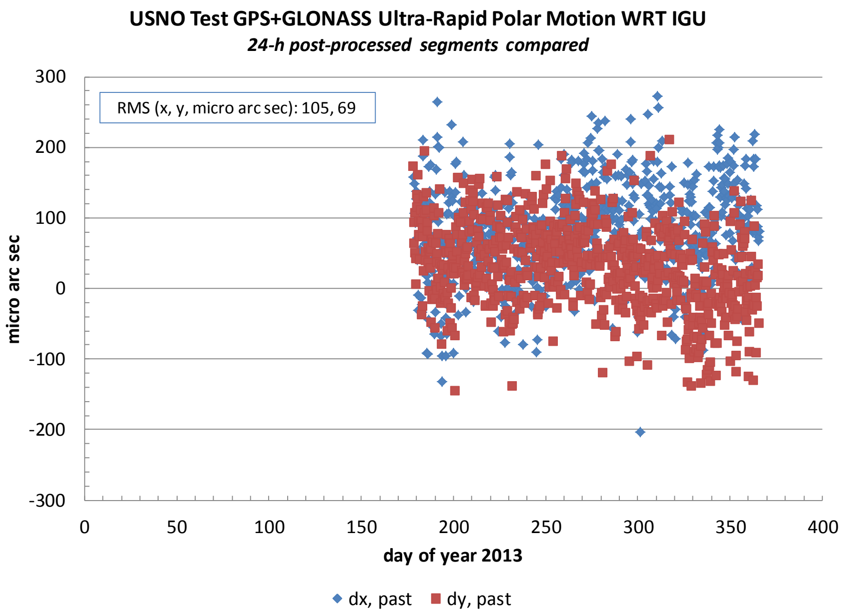

Figure 6: Difference between 24–h post–processed polar motion estimates in USNO test ultra–rapid GPS+GLONASS solution and IGS "IGU" GPS–only ultra–rapid solution, 2013.

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EUREF Permanent Network

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1 Introduction

The IAG (International Association of Geodesy) Regional Reference Frame sub–commission for Europe, EUREF, is responsible for defining, providing access and maintaining the European Terrestrial Reference System **(ETRS89) (Bruyninx et al. 2010). The EUREF key infrastructures are the EUREF Permanent GNSS Network (EPN)** and the United European Levelling Network (UELN). The EPN is a network of continuously operating GNSS reference stations maintained on a voluntary basis by EUREF members. Its primary purpose is to provide access to the ETRS89 by making publicly available the GNSS tracking data as well as the precise coordinates of all EPN stations. The EPN cooperates closely with the International GNSS Service (IGS, Dow et al. (2009)); EUREF members are involved in the IGS Governing Board, the IGS Real–Time Pilot Project, the IGS GNSS Working Group, the IGS Antenna Calibration Working Group, the Troposphere Working Group, the IGS Multi GNSS Experiment (MGEX), and the IGS Infrastructure Committee.

The EUREF Technical Working Group (TWG) defines the general policy of the EPN following proposals by the EPN Coordination Group. This Coordination Group consists of the Network Coordinator (managing the EPN Central Bureau), Data Flow Coordinator, Analysis Coordinator, Reference Frame Coordinator, Troposphere Coordinator, Chair of the Real–time Analysis project, and Chair of the Reprocessing Project.

This paper gives an overview of the main changes in the EPN over the year 2013.

2 Tracking Network

2.1 New Stations

By the end of 2013, the EPN network consisted of 246 continuously operating GNSS reference stations (Fig. 1) from which 32% also belong to the IGS. Before inclusion in the EPN, the EPN Central Bureau checks the data quality, meta–data, data availability and latency, and the availability of absolute antenna calibrations for the proposed station. These absolute antenna calibrations can be type mean calibrations (provided by the IGS) or individual calibrations (see Baire et al. (2013)). The antenna calibration file used within the EPN (ftp://epncb.oma.be/pub/station/general/epn_08.atx) contains these individual antenna calibrations complemented with the type mean calibrations from the IGS. End of 2013, individual calibrations were used at 59 EPN stations amongst which 19 (ANKR, BRUX, BUCU, BZRG, GANP, HOFN, METS, NICO, ORID, PENC, POTS, REYK, RIGA, SASS, SOFI, WARN, WROC, WTZR, and ZIM2) are also belonging to the IGS.

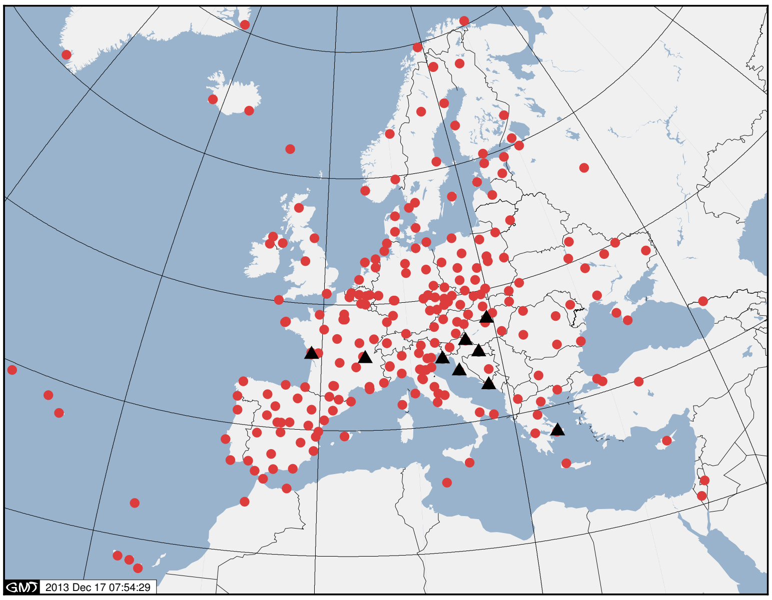

Figure 1: EPN tracking stations, status Dec. 2013. ▲ indicate new stations included in the network in 2013.

Table 1: New stations included in the EPN in 2013

4 char–ID	Location	Replacement or New	Sat. Tracking	Antenna Calibration used in EPN analysis
BRON	Bron, France	new (but already former)	GPS+GLO+GAL	Type mean from IGS
CAKO	Cakovec, Croatia	new	GPS+GLO	Type mean from IGS
DUB2	Dubrovnik, Croatia	DUBR	GPS+GLO	Type mean from IGS
DYNG	Dionysos, Greece	new	GPS+GLO+GAL	Type mean from IGS
ILDX	Ile d'Aix, France	new	GPS+GLO+GAL	Type mean from IGS
PEN2	Penc, Hungary	PENC (not yet former)	GPS+GLO+GAL	Individual from GEO++
PORE	Porec, Croatia	new	GPS+GLO	Type mean from IGS
POZE	Pozega, Croatia	new	GPS+GLO	Type mean from IGS
ZADA	Zadar, Croatia	new	GPS+GLO	Type mean from IGS

As soon as a station fulfils all requirements, it is included in the EPN. Data communication problems, influencing a reliable upload to the EPN data centres (regional and local ones) is one of the main reasons delaying the integration of a new station. However, almost all proposed stations are accepted within six months after their initial proposal. Interested station managers can check EPN guidelines for a proposed station to become an EPN site at http://epncb.oma.be/_networkdata/proposed.php.

Eight new stations were integrated in the EPN network in 2013: CAKO, DUB2, DYNG, ILDX, PEN2, PORE, POZE, and ZADA. They are indicated with triangles in Fig. 1. More details are provided in Tab. 1. Two of the stations are replacements of decommissioned EPN stations (mostly due to construction work near the antenna).

2.2 Multi–GNSS Tracking

All new stations added to the EPN in 2013 are equipped with GPS/GLONASS tracking equipment, bringing the percentage of the EPN stations providing GPS+GLONASS data to 73%. In addition, 96 EPN stations (Fig. 2) operate equipment that is certified "Galileo–ready", and 45 of them upload RINEX v3 data including Galileo observations to the data centre maintained by the BKG (Bundesamt für Kartographie und Geodäsie). The development is significant taking into account that in August 2008 only 8 and in March 2013 33 stations were delivering RINEX v3 data. At present, the most dominant Multi–GNSS contribution comes from Leica receivers. More than half of the data are not yet of format 3.02. The development of routine RINEX v3 quality checks, as shown in Fig. 4, is a primary requirement to enhance the EPN to a Multi–GNSS observing network.

In addition, 31 of the 33 new antennas/radomes (new stations or replacements at existing stations) introduced in the EPN during 2013 are capable of tracking new signals from

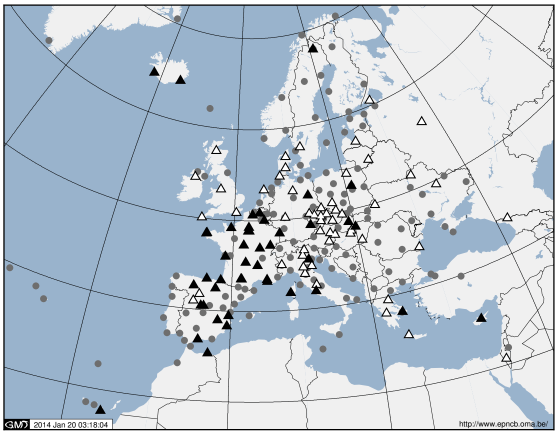

Figure 2: EPN tracking stations capable of tracking Galileo: ▲ submitting RINEX v3 data to EUREF; △ not (yet) submitting RINEX v3 data to EUREF.

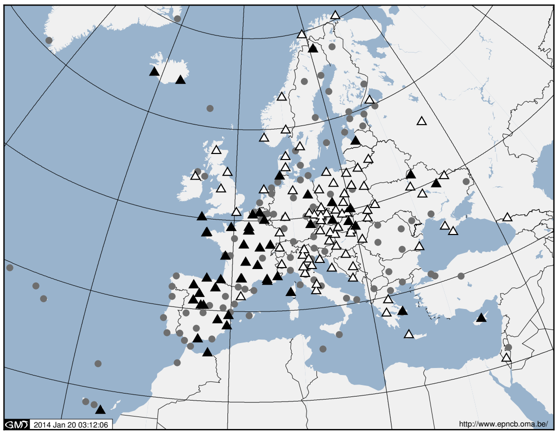

Figure 3: EPN tracking stations capable of tracking L5 indicated with △; those in addition including L5 in their RINEX v2.11 data are indicated by ▲.

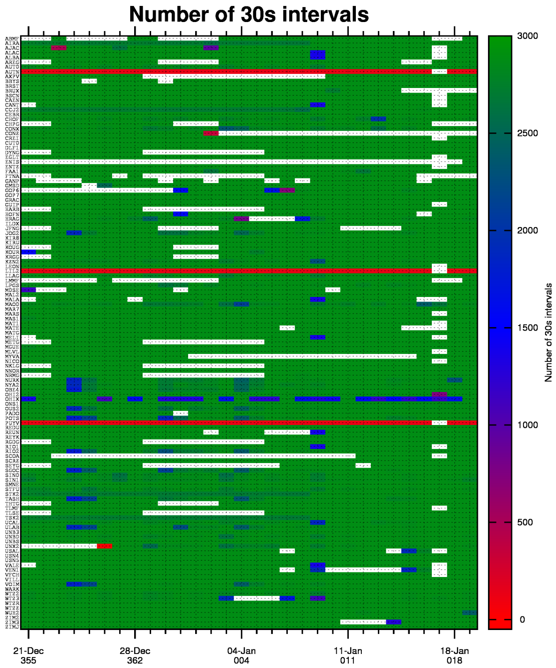

Figure 4: Completeness of RINEX v3 data of EPN (and MGEX) multi-GNSS stations (mid–September — mid–October 2013). Updated plots available under ftp://ftp.unibe.ch/aiub/mgex/plots/ep30.png.

multiple GNSS and will not require any additional hardware upgrade in the near future.

Already today 77 EPN stations have the capability of tracking GPS L5, 52 of them are actually providing RINEX v2.11 data including L5 (see Fig. 3).

2.3 Data flow

The EPN is working with three main data centers defined as regional data centers (RDC). The BKG and OLG (Austrian Academy of Sciences) data centers are responsible for the daily business while the data center of the EPN Central Bureau (Royal Observatory of Belgium) is the basis for the reprocessing activities hosting all historical EPN RINEX data with corrected meta–data.

All EPN stations routinely submit their data to BKG and OLG in predefined ways. Already before the recommendations of the IGS Workshop 2012, both RDCs accepted files with gzip compression (valid also for 64–bit UNIX and Windows). While the BKG RDC already processes and distributes EPN RINEX V3 and high rate data in separate directories, the OLG DC installed this functionality only for MGEX data, but will follow in 2014.

3 Data Analysis

3.1 New Analysis Combination Center

In March 2013, BKG announced H. Habrich would retire from his position as Analysis Center Coordinator. Consequently on April 4 the EUREF Technical Working Group issued a call for a new Coordinator. On May 28, 2013, the EUREF TWG accepted the proposal of a consortium between the Military University of Technology (MUT, Warsaw, Poland) and the Warsaw University of Technology (WUT) to act as the future Analysis Combination Center (ACC) for a period of 4 years. From June 1st, 2013 to May 31, 2015, K. Szafranek will be responsible of the ACC and from June 1st, 2015 to May 31, 2017 this task will be taken over by A. Araszkiewicz. Besides, the ACC team consists of M. Figurski (MUT) and T. Liwosz (WUT).

The most important task for the new ACC in 2013 was to prepare new scripts for the combination of the solutions provided by the EPN Local Analysis Centers (LAC). To preserve the continuity, these scripts were based on the previous work of H. Habrich. The main difference between the MUT/WUT and BKG combination is the reference frame (new solutions are tied to IGb08 instead of IGS08 for the old ones) and, as a consequence, the selection of the reference stations. Currently the alignment to IGb08 is carried out by adding minimally constrained conditions on 71 IGS stations. MUT/WUT also uses a slightly different method of excluding stations from the LACs contributions – usually it is a matter of 1 station when comparing BKG and MUT/WUT solutions. After an overlap period of 3 months and several tests confirming that the quality of the combined solution did not decrease in comparison to the hitherto delivered solutions, routine combinations by the MUT/WUT consortium will start with GPS week 1768 and published in the beginning of 2014.

The web page of the new ACC has also been prepared (http://www.epnacc.wat.edu.pl). Currently it presents mainly the details of the weekly combined solutions: comparison of station coordinates, Helmert transformation parameters for each LAC solution with reference to the combined solution and link to the full combination report available from the EPN Central Bureau (ftp://epncb.oma.be/pub/product/reports/). The weekly reports sent by LAC email have been shortened and now they contain only the most important information. The full combined solutions are still available from the BKG server (ftp://igs.bkg.bund.de/EUREF/products/).

3.2 Updated EPN Analysis Guidelines

To keep the EPN processing strategy up to date, several changes have been introduced into the "Guidelines for the EPN Analysis Centres", available from http://epncb.oma.be/_documentation/guidelines/guidelines_analysis_centres.pdf. First, final daily solutions became mandatory. Final weekly combined solutions are still the core EPN product sent to the IGS as its European densification, but the daily combinations are developed in parallel. To avoid overlapping among LACs and to prepare for the new challenges which the EPN faces, the LACs have been encouraged to consider a possible re–orientation of their contribution to the EPN. One of the LACs, GOP (Czech Republic) has already replied to this call and decided to focus on reprocessing activities instead of weekly routine submissions. This action required a re–distribution of several stations processed up to now by GOP LAC. Still, in general, not more than 5 LACs are accepted for one EPN station, but exceptions are allowed for twin stations.

The updated analysis guidelines also recommend to use orbits and clocks consistent with the analysis options and software used by each LAC (or to use combined IGS products) and require to exclude the defective satellites. Concerning troposphere parameter estimation, it is now mandatory to estimate hourly troposphere parameters for each station and it is recommended to submit tropospheric gradients (estimated using the Chen–Herring model (Chen and Herring 1997) or an equivalent model). The updated guidelines also introduce the requirement of using GMF (Böhm et al. 2006) or VMF (Böhm and Schuh 2004) mapping function to map the tropospheric delay. Within the discussion, the EUREF community stressed the need to develop a Troposphere SINEX format including gradients.

Several other processing options have been also updated. Starting with GPS week 1765 the elevation cut–off angle was set to 3° , application of atmospheric tidal loading corrections is recommended and it is mandatory to include 2nd order of ionospheric corrections and ionospheric ray bending corrections.

3.3 Routine Processing

A total of 17 Local Analysis Centres submit weekly free–network solutions (SINEX format) for an EPN subnetwork. The majority of the analysis centres used the *Bernese GPS software* Ver. 5.0, but in 2013, 11 LACs switched from Ver. 5.0 to Ver. 5.2 and applied the new analysis guidelines. GPS+GLONASS data are routinely analysed by 12 LACs. The EPN Analysis Combination Centre combines the subnetwork solutions into the daily and weekly combined EPN solutions. These solutions are tied to the most recent IGS realisation of the ITRS. They are used as input for the EPN Reference Frame Coordinator for the generation of a multi–year EPN solution which is updated each 15 weeks, and provides up–to–date EPN positions and velocities allowing the classification of EPN stations as:

- Class A stations with positions at 1 cm accuracy at all epochs of the time span of the used observations;
- Class B stations with positions at 1 cm accuracy at the epoch of minimal variance of each station.

Following the EUREF "Guidelines for EUREF Densifications" (Bruyninx et al. 2010), only Class A EPN stations can be used for densifications of the ETRS89.

In addition, a smaller group of LACs is also submitting a rapid solution that is provided less than 24 hours after the last observations and an ultra–rapid (hourly) solution provided about one hour after the last observations to the EPN Combination Centre. Here, the different solutions are combined into a rapid and an ultra–rapid EPN solution. The number of LACs submitting these solutions varies, currently 10 LACs upload rapid and 3 LACs upload ultra–rapid solutions.

Beside station coordinates, the 17 LACs also submit zenith total delay (ZTD) parameters on a routine basis. The ZTD parameters are delivered with a sampling rate of 1 hour, on a weekly basis but in daily files. Thanks to the growing computation power, the individual LACs could enlarge their respective network. This way, almost all EPN stations are processed by at least four LACs which improves, e.g., the outlier detection. The weekly mean bias and its standard deviation (Fig. 5 and 6) are well below the 2mm ZTD level since more than three years of routine operation.

Alongside the ZTD combination which gives insight into the agreement of the individual solutions to each other some inter–technique comparisons have been added to the web site of the EPN Central Bureau. The time series of differences of EPN ZTD estimates with respect to radiosonde–derived ZTDs are computed for almost 100 stations. For the stations considered the horizontal distance between radiosonde and GNSS location is varying from less than 1 km up to 70 km. The standard deviation of the differences is

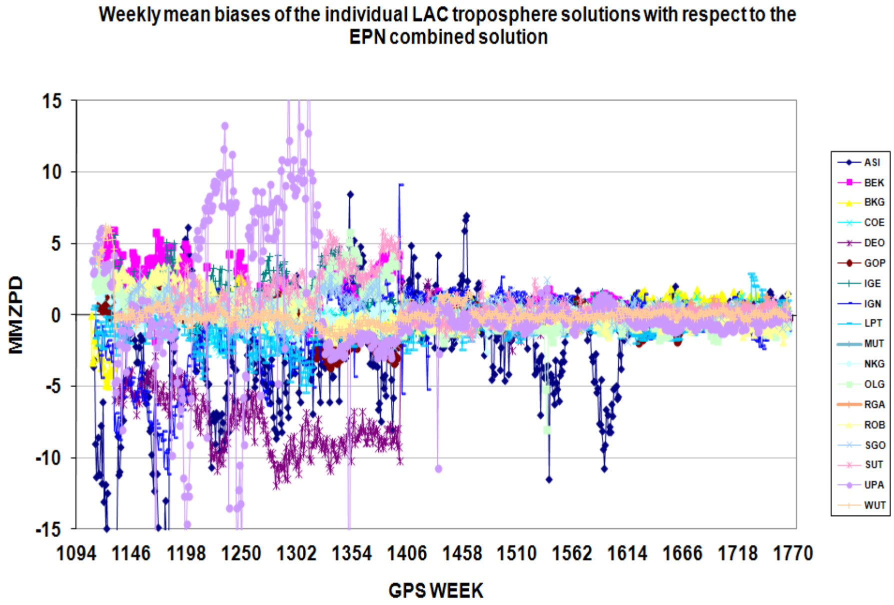

Figure 5: Weekly mean biases of LACs individual ZTD contributions w.r.t. the combined ZTD solution (mm ZTD); results from routine operation since June 2001.

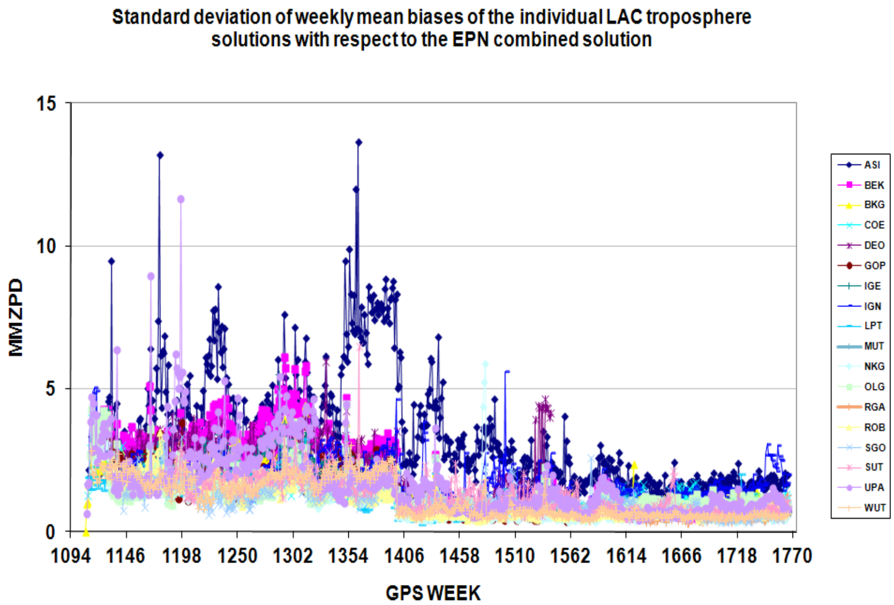

Figure 6: Standard deviation of weekly mean biases of LACs individual ZTD contributions w.r.t. the combined ZTD solution (mm ZTD); results from routine operation since June 2001.

between 4 and 19 mm ZTD. The difference time series for co–located VLBI stations are available for ten stations. Here the bias of the differences is in the range of 0.3 to −7.1 mm ZTD with standard deviation between 3.8 to 6.5 mm ZTD. It should be noted that the height difference between the sensors has not been taken into account for the plots. A more detailed comparison is given in Heinkelmann et. al (2013).

3.4 EPN Reprocessing

The first re–analysis of the complete EPN was concluded in 2012 under the name EPN–Repro1 (Völksen 2011). Already then it became clear that the reprocessing of the entire EPN will be a continuous task for the coming years, always related to the realization of a new reference system (e.g. ITRF2008) or significant improvements in the analysis strategies. Therefore it has been decided in the summer of 2013 to conduct a second reprocessing of the entire EPN under the name EPN–Repro2.

While in EPN–Repro1 almost the entire group of Local Analysis Centres participated, the focus of EPN–Repro2 lies on the generation of three entirely independent and complete EPN solutions based on *GAMIT* version 10.50 (King et al. 2010), *GIPSY* version 6.2 (Lichten et al. 1995), and *Bernese GNSS Software* version 5.2 (Beutler et al. (2007), Dach et al. (2013)). The analysis of historical GLONASS data is of large interest but this part of the analysis can only be carried out by *Bernese GNSS Software* (*NAPEOS* is not yet available to one of the participating LACs). These three solutions will be generated by three different LACs using one of the three mentioned software packages. Still, EPN–Repro2 is also open for the participation of other LACs.

The analysis of EPN–Repro2 will be performed as a regional network based on the reprocessed products provided by CODE and JPL, because other or the combined products of the *2nd IGS Reprocessing campaign* are not yet available. GNSS observation data will be made available by the EPN Central Bureau and are mandatory to be used. These data are cross–checked with the station logs of the GNSS sites and meet the current IGS standards. EPN–Repro2 will not completely follow the guidelines of the IGS but will be very much consistent to the routine processing of the EPN using the updated analysis guidelines. For example the EPN–Repro2 campaign will use the individual antenna calibrations and complement them with type mean calibrations.

A benchmark test has been designed consisting of 32 sites covering large parts of Europe. The test data cover a period of 4 weeks (1677–1688) with moderate and active ionospheric conditions to evaluate the performance of the different software packages. After successful completion of the benchmark, the entire EPN will be reanalyzed and the results are expected by the summer 2014.

3.5 Local Analysis Centers Workshop

The 8th EPN Local Analysis Centers Workshop was held in at the ROB (Royal Observatory of Belgium) in Brussels from May, 15 to 16, 2013. The workshop was preceded by a half–day tutorial on the *Bernese GNSS software* Ver. 5.2. With 37 participants, the workshop mainly focused on discussions related to the overdue update of the EPN analysis guidelines. The Minutes of the workshop are available from http://epncb.oma.be/_newseventslinks/workshops/EPNLACWS_2013/.

4 Densification of the IGS and EPN

The European IGS densification solution is a cumulative EPN solution which is routinely updated each 15 weeks, uses all available weekly EPN SINEX solutions from GPS week 834 on. The SINEX solutions before GPS week 1632 have been corrected to be compliant with the epn_08.atx/igs08.atx antenna calibration model. Since GPS week 1709, the EPN cumulative solution is tied to the IGb08.

The EPN/IGb08 densification product files (including a discontinuity table and associated residual position time series) can be downloaded from the
ftp://epncb.oma.be/pub/station/coord/EPN.

More details can be found in
http://epncb.oma.be/_productsservices/coordinates.

The densification of the EPN, using the dense national active GNSS networks, was continued. The main target of this work (beyond the homogenization of the national networks) is to compute a dense continental–scale velocity field to support an improved realization of the ETRS89. The product will be an important input for the IAG Working Group on “Integration of dense velocity fields into the ITRF” (Legrand et al. 2013). Most of the European countries are providing weekly SINEX solutions to the EPN Reference Frame Coordinator. By the end of 2013 the total number of stations exceeded 2000. These solutions are combined with the weekly EPN solution and then stacked to obtain a consistent cumulative position/velocity solution. Two contributions (IGN, France and BIGF, UK) are global solutions and therefore the densified EPN network will be considered as densification of the global IGS network as well. This work is still in progress (see Kenyeres et al. (2013)).

5 EPN Real–Time Analysis Project

The EPN Project on “Real–time Analysis” is focusing on the processing of the EPN real–time data to derive and disseminate real–time GNSS products (http://www.epncb.oma.

be/_organisation/projects/RT_analysis/).

EUREF's real–time resources have been contributing to the IGS Real–Time Service (IGS RTS) which has been launched in March 2013 (Caissy et al. 2013). Several EPN stations are permanently used for the orbit and clock correction processing within the IGS RTS by the various real–time analysis centers. Moreover, the IGS RTS products have been made available through the dedicated products broadcaster located at BKG (http://products.igs-ip.net).

In view of the successful launch of the new COST action on advanced GNSS processing and products for Meteorology and Climate (Jones et al. 2013) significant effort has been done in the derivation of real–time ZTD estimates using IGS and EUREF real–time resources (e.g. Douša and Václavovic (2013); Pacione and Söhne (2013)).

Since 2012, EUREF is broadcasting satellite orbit and clock corrections referred to the ETRS89 (realization ETRF2000). Two different data streams are available for the moment:

- EUREF01: corrections for GPS, sampling rate 5 seconds, coming from Kalman–filter based combination
- EUREF02: corrections for GPS+GLONASS, sampling rate 5 seconds, coming from Kalman–filter based combination

Together with the real–time broadcast ephemerides data stream, named RTCM3EPH, users can directly derive real–time coordinates referred to ETRS89 at the level of a few decimetres. These data streams are available from the three EUREF regional broadcasters at BKG (http://www.euref-ip.net and http://products.igs-ip.net), at ASI (http://euref-ip.asi.it:2101/), and at ROB (http://www.euref-ip.be).

6 Conclusions

Considerable progress has been made within the EUREF Permanent GNSS Network in 2013.

73% of the 246 EPN stations now track GLONASS in addition to GPS and 45 stations provide RINEX v3 including Galileo observations. Presently the EPN focusses on the development of routine RINEX v3 quality checks.

An EPN Local Analysis Centres Workshop was held in Brussels in May 2013. During the workshop the LAC discussed the introduction of new analysis guidelines.

A new Analysis Combination Centre was set up in the summer of 2013. Located at Warsaw, the MUT/WUT consortium will take over the routine combination of the EPN LAC products in January 2014.

In the fall of 2013, the updated analysis guidelines were introduced. They include the generation of a new daily final solution and the application of several state–of–the art GNSS modelling techniques.

Time series of differences of EPN zenith tropospheric delay estimates with respect to radiosonde–derived ZTDs are now made available at the EPN CB for almost 100 stations and in addition, the difference time series for co–located VLBI stations is provided for ten stations.

EPN–Repro2 is presently prepared. It will be based on three entirely independent and complete EPN solutions provided with *GAMIT*, *GIPSY* and *Bernese*. As a first step, a benchmark campaign is underway to test the analysis strategies and the setup of the three software packages. The results of EPN–Repro2 are expected for the summer of 2014.

Since GPS week 1709, the EPN cumulative solution is tied to the IGb08. In addition, a densification of the EPN is performed using weekly SINEX solutions provided by several European countries for their dense GNSS networks. These solutions are combined with the weekly EPN solution and then stacked to obtain a consistent cumulative position/velocity solution. The latest EPN densification already exceeds 2000 GNSS stations.

The EPN Real–Time Analysis Project is closely linked to the IGS Real–Time Service at both the station level as the level of product distribution. EUREF is also broadcasting satellite orbit and clock corrections allowing users to derive real–time coordinates in the ETRS89 at few decimetres level.

More information on the EPN: http://www.epncb.oma.be/.

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1 The SIRGAS reference frame

The realisation of SIRGAS (Sistema de Referencia Geocéntrico para las Américas) is a regional densification of the International Terrestrial Reference Frame (ITRF) (e.g., SIRGAS (1997), Drewes et al. (2005), Sanchez and Brunini (2009)). At present, it is composed of GNSS stations only; other geodetic space techniques like VLBI, SLR or DORIS are not involved yet. To guarantee the appropriate maintenance of the reference frame, SIRGAS comprises (Fig. 1):

- One core network (SIRGAS–C) composed of a set of geographically well–distributed and consistently reliable reference stations. The main objective of the SIRGAS–C network is to ensure the long–term stability of the reference frame, and it is understood as the primary densification of the ITRF in Latin America and the Caribbean.
- National reference networks (SIRGAS–N) realising densifications of the core network. The central purpose of these densifications is to provide accessibility to the reference frame at national and local levels and to facilitate its extension by assimilating new reference stations (mainly those installed by the national agencies responsible for the local reference networks).

The SIRGAS reference frame is calculated weekly. The SIRGAS–C network is processed by the Deutsches Geodätisches Forschungsinstitut (DGFI, Germany) since this institute acts as the IGS Regional Network Associate Analysis center for SIRGAS (IGS RNAAC SIR, Sanchez (2012), (2013)). The SIRGAS–N networks are computed by the SIRGAS Local Processing centers, which operate under the responsibility of national Latin American organisations. At present, the SIRGAS Local Processing centers are: CEPGE (Ecuador), CPAGS–LUZ (Venezuela), IBGE (Brazil), IGAC (Colombia), IGM–Cl (Chile), IGN–Ar (Argentina), INEGI (Mexico), and SGM–Uy (Uruguay). These processing centers deliver

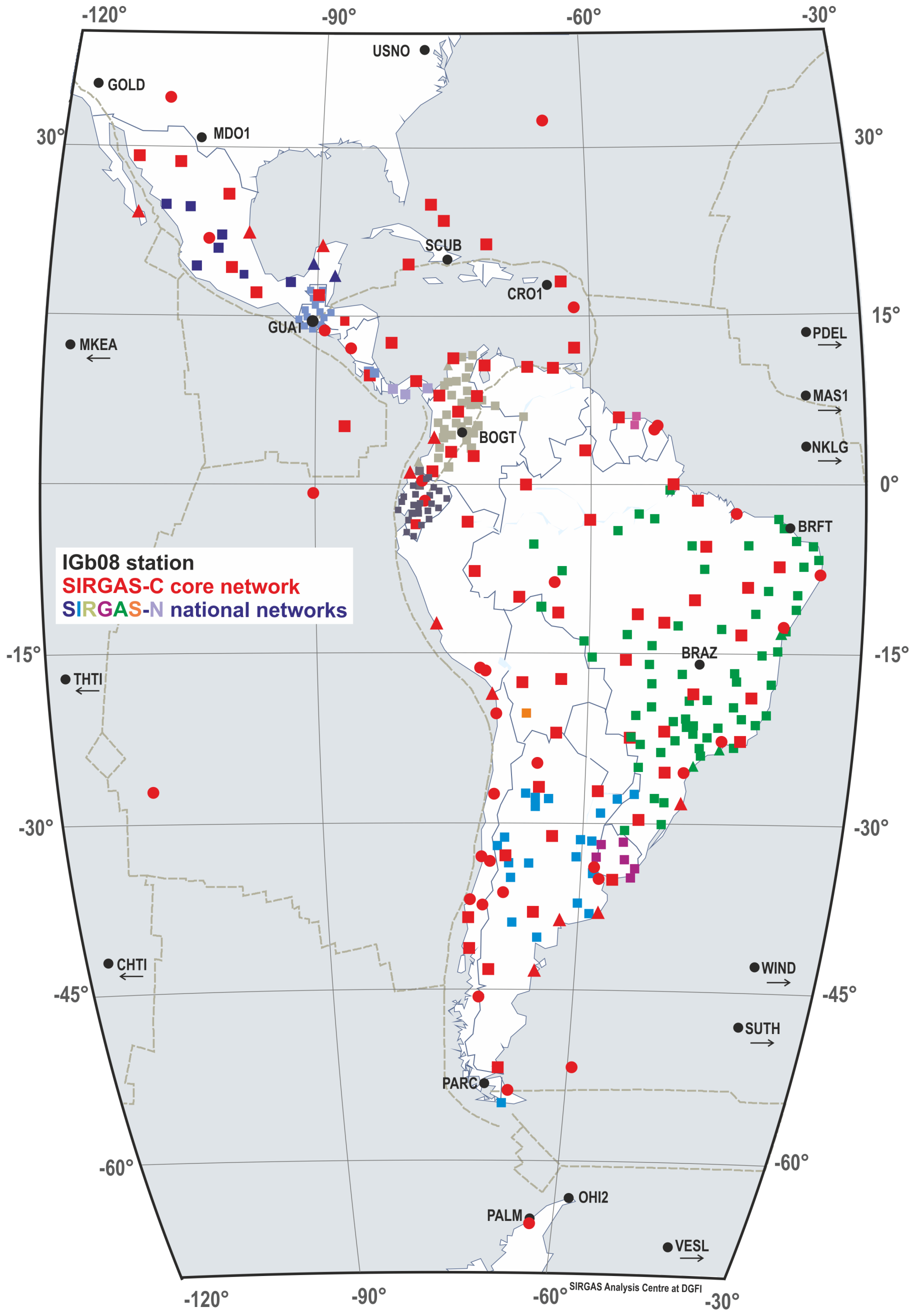

Figure 1: SIRGAS network (as of December 2013).

loosely constrained weekly solutions for the SIRGAS–N national networks, which are combined with the SIRGAS–C core network to get homogeneous precision for station positions and velocities. The individual solutions are combined by the SIRGAS Combination centers currently operated by DGFI (Germany) and IBGE (Brazil).

2 Routine processing of the SIRGAS reference frame

The SIRGAS processing centers follow unified standards for the computation of the loosely constrained solutions (e.g., Costa et al. (2012), Natali et al. (2009), Seemüller et al. (2012)). These standards are generally based on the conventions outlined by the IERS and the GNSS–specific guidelines defined by the IGS; with the exception that in the individual SIRGAS solutions the satellite orbits and clocks as well as the Earth orientation parameters (EOP) are fixed to the final weekly IGS values (SIRGAS does not compute these parameters), and positions for all stations are constrained to ±1 m (to generate the loosely constrained solutions in SINEX format). INEGI (Mexico) and IGN–Ar (Argentina) employ the software GAMIT/GLOBK (Herring et al. 2010); the other local processing centers use the *Bernese GPS Software* Ver. 5.0 (Dach et al. 2007). At the moment, the SIRGAS Local Processing centers align their procedures to the new standards described in the IERS Conventions 2010 (Petit and Luzum 2010) and to the characteristics specified by the IGS for the second reprocessing of the IGS global network (`http://acc.igs.org/reprocess2.html`). The IGS RNAAC SIR applies these new standards since July 2013 and is employing the *Bernese GNSS Software* Ver. 5.2 (Dach et al. (2007), (2013)). It is expected that the other processing centers start delivering solutions based on the new standards in January 2014.

3 Kinematics of the SIRGAS reference frame

To estimate the kinematics of the SIRGAS reference frame, a cumulative (multi–year) solution is computed (updated) every year, providing epoch positions and constant velocities for stations operating longer than two years. As the introduction of ITRF2008 (i.e. IGS08/IGb08) as the reference frame for the generation of the IGS products caused a discontinuity of some mm in the station position time series, the computation of multi–year solutions for the SIRGAS reference frame was discontinued until getting weekly normal equations referring to the ITRF2008 and covering a time span of at least three years. It is decided that SIRGAS will reprocess the entire SIRGAS network following IGS procedures and applying the new standards from January 1997 to present. However, while the SIRGAS Local Processing centers are unable to apply these, a new multi–year solution was computed for the SIRGAS–C core network only, i.e., for the stations processed routinely by the IGS RNAAC SIR. Main objective of this multi–year solution is to identify possible secular effects caused by the Maule earthquake of February 2010 in the kinematics of the

SIRGAS reference frame.

4 New processing standards for the SIRGAS reference frame

The standards applied for the generation of the weekly free normal equations for the new cumulative SIRGAS solution are:

- Basic observable: ionosphere–free linear combination;
- Sampling rate: 30 sec;
- Elevation cut–off angle: 3 deg;
- Elevation–dependent weighting of observations: $1/\cos^2 z$, with z being the zenith distance;
- Satellite orbits, satellite clock offsets, and EOP fixed to the combined IGS weekly solutions (Dow et al. (2009), http://www.igs.org/components/prods.html) referring to the IGS08/IGb08 frame. Since the IGS products refer to IGS08/IGb08 since April 2011 (GPS week 1632), the normal equations for previous weeks (backwards until April 2010) were computed using the satellite products and EOP generated by the IGS processing center CODE (center for Orbit Determination in Europe, ftp://ftp.unibe.ch/aiub/CODE/);
- Application of antenna phase center offsets and direction–dependent phase center variation values consistent with the IGS08/IGb08 frame for both transmitting and receiving antennas; i.e., spacecraft–specific z–offsets, block–specific x– and y–offsets, and phase center variations for receiver and satellite antennas from model igs08.atx (Schmid et al. (2007), http://igs.org/igscb/station/general/pcv_archive);
- Antenna radome calibrations applied if given in the model igs08.atx. Otherwise, the radome effect is neglected and the standard antenna model (radome NONE) is used;
- Phase ambiguities for L1 and L2 solved using the quasi–ionosphere free (QIF) strategy of the *Bernese GNSS Software* Ver. 5.2 (Dach et al. 2007). In this step, the ionosphere models of CODE (ftp://ftp.unibe.ch/aiub/CODE/) are provided as input to increase the number of solved ambiguities;
- The tropospheric zenith delay is modelled using the Vienna Mapping Function 1 (VMF1, Böhm et al. (2006)). The a priori values (∼ dry part) are derived from gridded coefficients based on the climate numerical models of ECMWF (European center for Medium–Range Weather Forecasts) and made available by J. Böhm, TU Vienna, at http://ggosatm.hg.tuwien.ac.at/DELAY/GRID/VMFG/. These a priori values are refined by computing partial derivatives of the troposphere zenith delay parameters (∼ wet part) with 2h intervals (using also VMF1) within the network adjustment. In addition, to model azimuthal asymmetries, horizontal gradient pa-

rameters are estimated according to the model of Chen and Herring (1997);

- Tidal corrections for solid Earth tide, permanent tide, and solid Earth pole tide are applied as described in Petit and Luzum (2010). The ocean tide loading is reduced with the FES2004 model (Letellier 2004) and the atmospheric tidal loading caused by the semidiurnal constituents S1 and S2 is reduced following the model of van Dam and Ray (2010). The reduction coefficients for the ocean tide loading are provided by M.S. Bos and H.–G. Scherneck at `http://holt.oso.chalmers.se/loading`. The reduction coefficients for the atmospheric tidal loading are provided by T. van Dam at `http://geophy.uni.lu/ggfc-atmosphere/tide-loading-calculator.html`
- Ocean or atmospheric tide geocenter coefficients are not applied since this correction is already contained in the final IGS (and CODE) products;
- Non–tidal loadings as atmospheric pressure, ocean bottom pressure, or surface hydrology are not reduced;
- Daily free normal equations are computed by applying the double difference strategy using the *Bernese GNSS Software* Ver. 5.2 (Dach et al. (2007), (2013)). The baselines are created taking into account the maximum number of common observations for the associated stations;
- The seven daily free normal equations corresponding to a GPS week are combined for computing a weekly free normal equation. Stations with large residuals in any daily normal equation (more than ±20 mm in the horizontal component or more than ±30 mm in the vertical component) are reduced from the corresponding daily equation and the weekly combination is recomputed.

5 Multi–year solution SIR13P01

The input data for this new cumulative solution are the weekly free normal equations covering the time span from April 2010 (GPS week 1580) to June 2013 (GPS week 1744). Given that most of the existing ITRF stations in South America are affected by the earthquake in Chile in February 2010 (see e.g. Sánchez et al. 2013), further stations located in Europe, Africa, Oceania and North America (Fig. 2) are included in the SIRGAS computations to increase the availability of fiducial points.

Before combining the weekly normal equations, a time series analysis is performed to identify outliers and discontinuities in the station positions. The thresholds for outliers are defined by ±15 mm for north and east and ±30 mm for height (about fourfold the mean RMS). If outliers appear sporadically (without pattern), the station is reduced from the respective free normal equation. If outliers reflect a discontinuity, a new position is set up for the station. Once outliers are reduced and discontinuities are identified, the weekly normal equations are combined to a multi–year solution setting up constant station

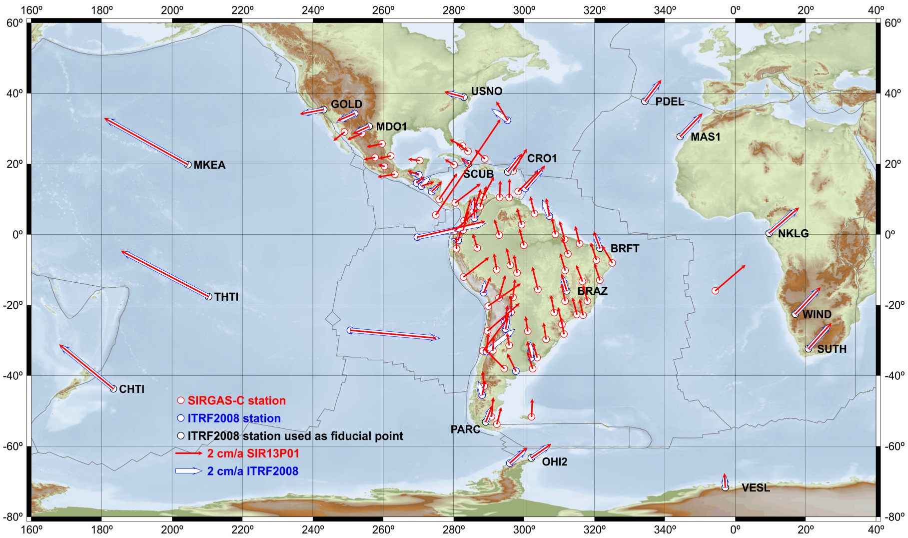

Figure 2: Horizontal velocities of the SIRGAS multi–year solution SIR13P01: it covers the time span from April 2010 to June 2013, includes 108 SIRGAS core stations and refers to ITRF2008, epoch 2012.0. (Stations with labels are fiducial points).

velocities (i.e. only linear station position variations are considered). The geodetic datum is realised by applying not–net–rotation and not–net–translation conditions with respect to the ITRF2008 coordinates (Altamimi et al. 2011) of selected IGb08 reference stations (Fig. 2). This procedure is carried out using the *Bernese GNSS Software* Ver. 5.2 (Dach et al. 2007)

The result of this computation is called solution SIR13P01 (Fig. 2). It includes positions and velocities for 108 SIRGAS core stations referring to the ITRF2008, epoch 2012.0. Its estimated precision is ±1.4 mm (horizontal) and ±2.5 mm (vertical) for the station positions at the reference epoch, and ±0.8 mm/yr (horizontal) and ±1.2 mm/yr (vertical) for the constant velocities. Stations showing very irregular post–seismic movements, like CONZ (Concepción, Chile) or ANTC (Antuco, Chile), are excluded because constant velocities (linear movements) are insufficient to model their behaviour (Fig. 3).

To evaluate the reliability of the SIR13P01 solution, different comparisons were performed (Tab. 1). The first comparison concentrates on the dissimilarities of the station positions and velocities at the fiducial points, i.e. the ITRF2008 values are compared with the values obtained in the SIR13P01 solution for the reference stations. The same procedure is repeated in a second comparison, but only taking into account those ITRF stations that were not used as fiducial points. Finally, the third comparison collates station position and velocities of the present solution with those values estimated in the last SIRGAS multi–year solution computed before the earthquake in February 2010 (i.e. the SIR10P01 solution, Seemüller et al. (2010)). The first and the second comparisons show the agreement between the new SIRGAS solution and ITRF2008; the third comparison should provide information

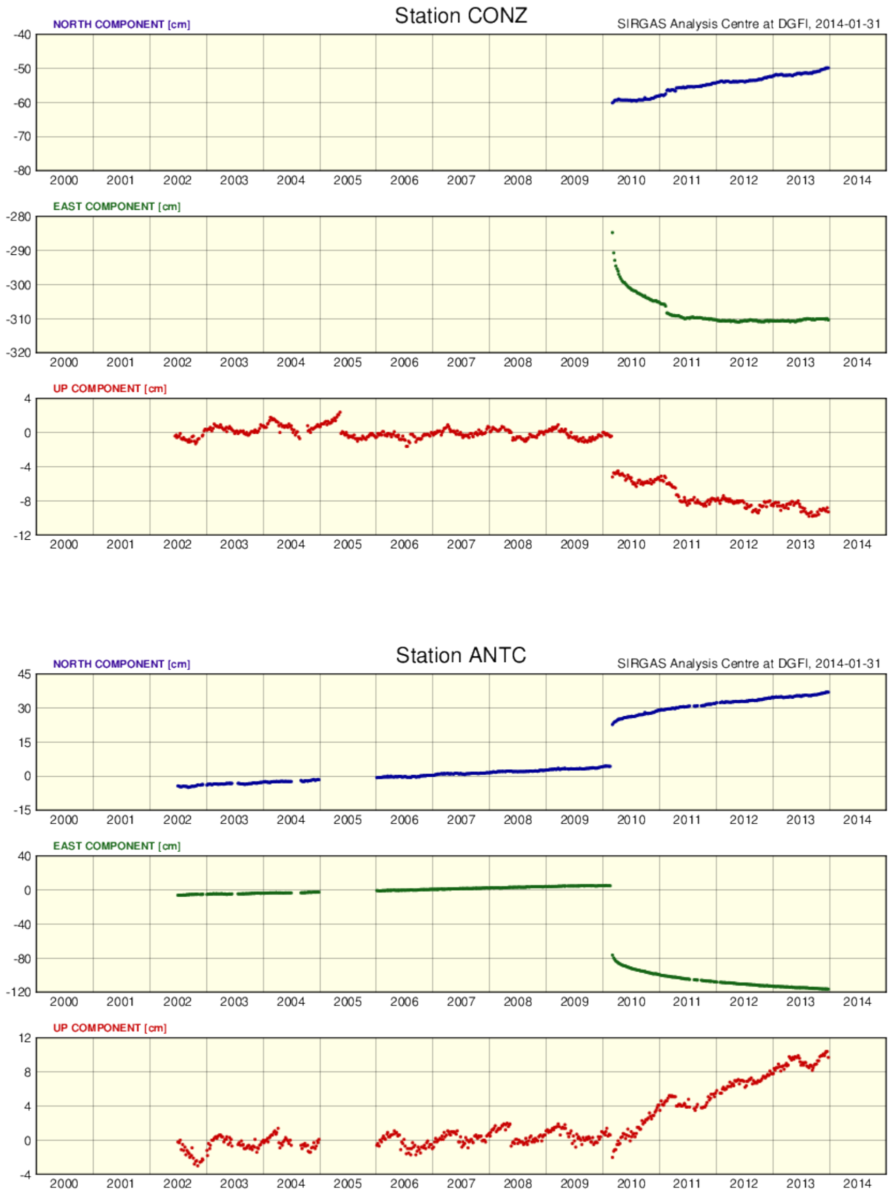

Figure 3: Time series of stations strongly affected by the Chilean earthquake in February 2010 (Concepción and Antuco).

Table 1: Comparison of the present SIR13P01 solution with ITRF2008 and the former solution SIR10P01 (computed before the Chilean earthquake in February 2010)

	Position [mm]			Velocity [mm/yr]		
	N	E	U	N	E	U
Comparison with ITRF2008, fiducial points only						
RMS	±3.2	±3.1	±3.8	±0.6	±1.1	±1.3
Mean	0.2	0.9	–0.9	–0.3	–0.1	0.6
Min	–6.5	–4.3	–7.8	–1.8	–2.0	–2.3
Max	4.6	8.3	7.0	1.8	1.9	2.4
Comparison with ITRF2008, non–fiducial points						
RMS	±8.2	±12.4	±13.7	±1.3	±3.2	±3.4
Mean	–0.1	9.8	–7.2	1.3	–0.3	–2.1
Min	–21.8	–25.8	–29.0	–3.1	–19.8	–8.9
Max	14.5	25.7	37.0	6.3	7.4	7.9
Comparison with SIR10P01						
RMS	±21.4	±39.5	±20.2	±1.3	±2.0	±2.7
Mean	–3.6	8.3	–5.9	1.0	–1.2	–1.3
Min	–88.3	–51.2	–26.2	–4.3	–19.8	–8.3
Max	130.5	588.3	130.59	6.8	3.7	11.5

about changes in the SIRGAS frame caused by the strong earthquake in Chile.

The discrepancies (for station positions and velocities) at fiducial points are within the coordinate accuracy of the ITRF2008 solution. Therefore, one could conclude that the new SIRGAS solution is appropriately aligned to this frame and it can be considered as its regional densification in Latin America and the Caribbean. The magnitudes obtained from the other two comparisons are on the contrary very large, in particular in the East component (Fig. 4). This means that older reference frame solutions (ITRF2008 or SIR10P01) differ significantly from the new realisation. Main reasons for this disagreement are:

- ITRF2008 and SIR10P01 do not reflect the effects (co–seismic and post–seismic movements) caused by the earthquake of February 2010 in the Southern part of

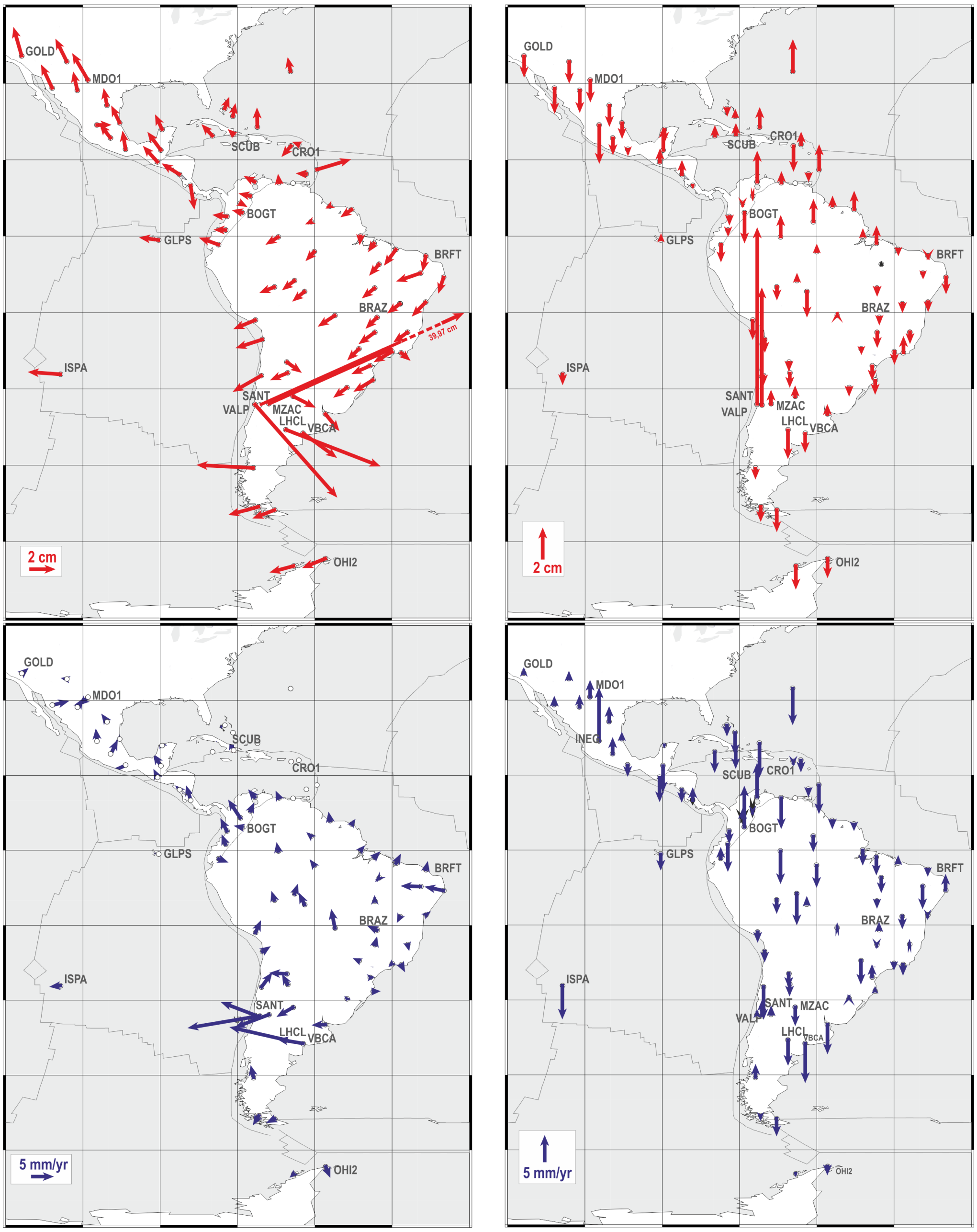

Figure 4: Horizontal (left) and vertical (right) residual position (upper two figures) and velocity (lower two figures) vectors between the SIR10P01 (before the earthquake in February 2010) and the SIR13P01 solutions.

South America;

- The weekly input solutions for ITRF2008 and SIR10P01 were computed with respect to the IGS05 frame, while SIR13P01 was computed with respect to the IGS08/IGb08 frame;
- Troposphere effects in SIR10P01 and SIR13P01 are modelled differently. Although the atmosphere parameters estimated within the network adjustment (∼ wet part) are very similar (some mm of discrepancy), the a priori zenith delay values (∼ dry part) differ by up to 5 cm, especially at those stations located in the tropical region;
- The datum realisation in SIR10P01 and SIR13P01 is based on different fiducial points. While the old solution includes reference stations located in Latin America only, the new solution also comprises reference stations located several thousand km away.

6 Outlook

Immediate plans concentrate on the reprocessing of the weekly SIRGAS normal equations backwards until January 1997 applying the new standards and considering the entire network. Therefore, the IGS RNAAC SIR takes care of the computations from 1997 until August 2008, when the first SIRGAS Local Processing centers started operating. From September 2008 until December 2013, the reprocessing includes the combination of the individual (reprocessed) solutions delivered by the SIRGAS Local Processing centers for the SIRGAS–N national networks.

7 Acknowledgements

The operational infrastructure and results described in this report are only possible thanks to the active participation of many Latin American and Caribbean colleagues, who not only make the measurements of the stations available, but also operate SIRGAS Analysis centers processing the observational data on a routine basis. This support and that provided by the International Association of Geodesy (IAG) and the Pan–American Institute for Geography and History (PAIGH) is highly appreciated. More details about the activities and new challenges of SIRGAS, as well as institutions and colleagues working on can be found at http://www.sirgas.org.

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Part III

Data Centers

IGS Infrastructure Committee Technical Report 2013

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1 Introduction

The Infrastructure Committee (IC) was established in March 2009 and is set with the task of studying and advising on infrastructure issues to the IGS Governing Board and the IGS Network Coordinator (NC). The latest status and recent progress of the Committee are detailed below.

2 Membership

Current Members appointed 3 April, 2011 for terms up to December 2013:

- Carine Bruyninx (ROB)
- Lou Estey (UNAVCO)
- Gary Johnston (GA)
- Nacho Romero – Chairman – (ESOC)
- Mike Schmidt (NRCan)
- Georg Weber (BKG)

Ex–officio Members:

- Steve Fisher – Central Bureau
- Jake Griffiths – Analysis Center Coordinator
- Mark Caissy – Real time Working Group Chair
- Bruno Garayt – Reference Frame Coordinator
- Carey Noll – Data Center Working Group Chair
- Ken Senior – Clock Products Coordinator

3 Charter

The Charter remains the same as published here:

http://igs.org/organization/iccharter.html

4 Summary of Activities in 2013

During 2013 the IC has been involved in many different activities as detailed below:

- **Site guidelines** produced by the IC were finally accepted and published through http://igs.org/network/guidelines/guidelines.html.
- Continued to support the **radome–off study at co–located sites** for closure in December 2013. Added stations, ONSA and LHAZ, in the study increased the number of participating stations to 10. (See Tab. 1.)

  During the year 2013, solutions using Network PPP have been produced and coordinated by the IC and the Reference Frame WG has analyzed the entire time series. The results and conclusions of the study will be presented in a poster at the AGU Fall 2013 meeting.

  The final conclusion is that it is not possible to extract the radome effect at most stations from the global post-processing, even when applying correction models due to EQ relaxing, etc.
- Investigating the **NGA station data**. After resolving the new ITT antenna calibration issues for GPS, the data was processed in network PPP mode and a draft

Table 1: List of stations participating in the radome–off study

Station	Radome Removal	Re–installation	Antenna	
CRO1	01 Apr. 2011	24 Jun. 2011	ASH701945G_M	JPLA
TSKB	01 Jul. 2011	30 Aug. 2011	AOAD/M_T	DOME
TSK2	01 Jul. 2011	30 Aug. 2011	AOAD/M_T	DOME
AREQ	19 Aug. 2011	03 Feb. 2012	AOAD/M_T	JPLA
FAIR	28 Apr. 2012	04 Aug. 2012	ASH701945G_M	JPLA
YAR2	28 Apr. 2012	28 Sep. 2012	AOAD/M_T	JPLA
GODE	06 Jul. 2012	13 Dec. 2012	AOAD/M_T	JPLA
MDO1	22 Feb. 2013	09 Aug. 2013	AOAD/M_T	JPLA
ONSA	28 Aug. 2013	06 Nov. 2013	AOAD/M_B	OSOD
LHAZ	12 Sep. 2013	11 Feb. 2014	ASH701941.B	SNOW

report is available and has been circulated in the IC. The data processing is fine in un-differenced mode and ambiguity fixing proceeds normally. Unfortunately in double difference mode the NGS analysis confirms that the NGA data is not correctly fixed of 1/2 cycle problems. It is not clear how this issue could be resolved and conversations continue with NGA and their contractors. The data will therefore NOT be merged soon with the regular data repository at CDDIS. The data is available publicly in CDDIS in a dedicated area.

- In terms of **RINEX 2/RINEX 3** the IC has been monitoring the recent problems with the RINEX 3 definition and implementation by different means (binary translation, BNC, etc). Also, we are keeping the IGS community informed of the recent Rx2.11 unofficial "extension" which is for experimental use.
- The IGS 2012 **Workshop IC recommendations** have been addressed and advanced.
- Two **IC telecons** have been held with good attendance across IC members and with the raising of minutes and traceable actions.
- The IC has supported the **RTPP in terms of data streaming** and the NULL–ANTENNA issue, where certain antennas correct the antenna phase center variations directly on the streamed measurements, which is completely NOT allowed for RINEX integration.

5 Strategic Plan Impact

- The strategic Plan impact has been correctly filled out online.

6 Plan for 2014

- Over the next year, the IC will ensure that all the 2012 recommendations are addressed.
- The IC will continue to support transversally the IGS across all services, pilot projects and experiments in infrastructure issues as they are discovered or brought up to our attention.
- The IC will prepare and coordinate a poster session for the 2014 Workshop and plans to hold a dedicated meeting during that week.

CDDIS Global Data Center Technical Report 2013

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1 Introduction

The Crustal Dynamics Data Information System (CDDIS) is NASA's data archive and information service supporting the international space geodesy community. For over 30 years, the CDDIS has provided continuous, long term, public access to the data (mainly GNSS–Global Navigation Satellite System, SLR–Satellite Laser Ranging, VLBI–Very Long Baseline Interferometry, and DORIS–Doppler Orbitography and Radiopositioning Integrated by Satellite) and products derived from these data required for a variety of science observations, including the determination of a global terrestrial reference frame and geodetic studies in plate tectonics, earthquake displacements, volcano monitoring, Earth orientation, and atmospheric angular momentum, among others. The specialized nature of the CDDIS lends itself well to enhancement to accommodate diverse data sets and user requirements. The CDDIS is one of NASA's Earth Observing System Data and Information System (EOSDIS) distributed data archive centers; EOSDIS data centers serve a diverse user community and are tasked to provide facilities to search and access science data and products.

The CDDIS serves as one of the primary data centers and core components for the geometric services established under the International Association of Geodesy (IAG), an organization that promotes scientific cooperation and research in geodesy on a global scale. The system has supported the International GNSS Service (IGS) as a global data center since 1992. The CDDIS activities within the IGS during 2013 are summarized below; this report also includes any recent changes or enhancements made to the CDDIS.

2 System Description

The CDDIS archive of IGS data and products are accessible worldwide through anonymous ftp. The CDDIS is located at NASA's Goddard Space Flight Center (GSFC) and is available to users 24 hours per day, seven days per week.

The CDDIS computer system is fully redundant with the primary and secondary/failover system. Each system utilizes a distributed functionality (incoming, outgoing, processing, database, and map servers) and is configured with a local backup system as well as a full backup system located in a third building at GSFC. The archive is equipped with a multi–Tbyte RAID storage system and is scaled to accommodate future growth. All ftp and web access is performed on the outgoing server. Data centers, stations, and analysis centers push files to the CDDIS incoming server. Processing of incoming files for the on–line archive is performed in a separate environment that also includes a database server for managing metadata extracted from incoming data.

3 Archive Content

As a global data center for the IGS, the CDDIS is responsible for archiving and providing access to GNSS data from the global IGS network as well as the products derived from the analyses of these data in support of both operational and working group/pilot project activities. The CDDIS archive is approximately 7.9 Tbytes in size of which 7.5 Tbytes are devoted to GNSS data, products (300 Gbytes), and ancillary information. All data and products are accessible through subdirectories of `ftp://cddis.gsfc.nasa.gov/gnss` (a symbolic link to `ftp://cddis.gsfc.nasa.gov/gps`).

3.1 GNSS Tracking Data

The user community has access to GNSS data available through the on–line global data center archives of the IGS. Over 50 operational and regional IGS data centers and station operators make data (observation, navigation, and meteorological) available in RINEX format to the CDDIS from selected receivers on a daily, hourly, and sub–hourly basis. The CDDIS also accesses the archives of the other three IGS global data centers, Scripps Institution of Oceanography (SIO) in California, the Institut Géographique National (IGN) in France, and the Korea Astronomy and Space Science Institute (KASI) to retrieve (or receive) data holdings not routinely transmitted to the CDDIS by an operational or regional data center. Tab. 1a and Tab. 1b below summarizes the types of IGS operational GNSS data sets archived at the CDDIS.

Data, in RINEX V2.10 or V2.11 format, from GPS and GPS+GLONASS receivers are archived within the main GNSS directory structure `/gnss/data`.

Table 1a: GNSS Data Type Summary

Data Type	Sample Rate	Data Format	AvailableOn–line
Daily GNSS	30 sec.	RINEX and compact RINEX	Since 1992
Hourly GNSS	30 sec.	Compact RINEX	10+ years
High–rate GNSS	1 sec.	Compact RINEX	Since May 2001
Satellite GPS	10 sec.	Compact RINEX	Since 2002

Table 1b: GNSS Data Archive Summary for 2013

Data Type	Avg. No. Sites/Day	Avg. Volume/Day	Total Volume/Year	Directory Location	Latency of Majority of Data
Daily GNSS	475	1100 Mb	400 Gb	`/gnss/data/daily`	Within 1 hour
Hourly GNSS	290	383 Mb	140 Gb	`/gnss/data/hourly`	Within 10 min.
High–rate GNSS	155	1900 Mb	695 Gb	`/gnss/data/highrate`	Within 10 min.
On–board GPS	1	0.5 Mb	200 Mb	`/gnss/data/satellite`	Within 10 days

The CDDIS archives four major types/formats of GNSS data, all in RINEX format, as described in Tab. 1a. Daily RINEX data are quality–checked, summarized, and archived to public disk areas in subdirectories by year, day, and file type; the summary and inventory information are also loaded into an on–line database. Nearly 153K daily station days from 520 distinct GNSS receivers were archived at the CDDIS during 2013. A complete list of daily, hourly, and high–rate sites archived in the CDDIS can be found in the yearly summary reports at URL ftp://cddis.gsfc.nasa.gov/reports/gnss/.

Within minutes of receipt, the hourly GNSS files are archived to subdirectories by year, day, and hour. These data are retained on–line indefinitely; the daily files delivered at the end of the UTC day contain all data from these hourly files and thus can be used in lieu of the individual hourly files. A total of 360 hourly sites (4.5M files) were archived during 2013.

High–rate (typically 1–second sampling) GNSS data are archived in files containing fifteen minutes of data and in subdirectories by year, day, file type, and hour. Many of these data files are created from real–time streams. Data from 175 high–rate sites (4.8M files) were also archived in the CDDIS in 2013.

The CDDIS generates global broadcast ephemeris files (for both GPS and GLONASS) on an hourly basis. These files are derived from the site–specific ephemeris data files for each day/hour. These files are appended to a single file that contains the orbit information for all GPS and GLONASS satellites for the day up through that hour. The merged ephemeris data files are then copied to the day's subdirectory within the hourly data file system. Within 1–2 hours after the end of the UTC day, after sufficient station–specific

Table 2: GNSS MGEX Data Archive Summary for 2013

Data Type	Average No. Sites/Day	Average Volume/Day	Directory Location
Daily GNSS	100	450 Mb	`/gnss/data/campaign/mgex/daily`
Hourly GNSS	50	90 Mb	`/gnss/campaign/mgex/data/hourly`
High–rate GNSS	35	850 Mb	`/gnss/campaign/mgex/data/highrate`

navigation files have been submitted, this concatenation procedure is repeated to create the daily broadcast ephemeris files (both GPS and GLONASS), using daily site–specific navigation files as input. The daily files are copied to the corresponding subdirectory under the daily file system. Users can thus download this single, daily (or hourly) file to obtain the unique navigation messages rather than downloading multiple broadcast ephemeris files from the individual stations.

The CDDIS generates and updates status files, (`/gnss/data/daily/YYYY/DDD/YYDD` status) that summarize the holdings of daily GNSS data. These files include a list of stations. The archive status files of CDDIS GNSS data holdings reflect timeliness of the data delivered as well as statistics on number of data points, cycle slips, and multipath. The user community can receive a snapshot of data availability and quality by viewing the contents of such a summary file.

The CDDIS successfully submitted a proposal to the IGS Multi–GNSS Experiment (MGEX) call for proposals for archive and distribution of data and products. During 2013 the CDDIS continued the archiving of data from participating multi–GNSS receivers as well as products derived from the analysis of these data. The data include newly available signals (e.g., Galileo, QZS, SBAS, and Beidou). The summary of the MGEX data holdings at the CDDIS is shown in Tab. 2. Daily status files are also provided that summarize the MGEX data holdings; however, data quality information available for operational GNSS data holdings is not available through this software.

The GPS Directorate conducted the first test transmission of CNAV (civilian navigation) messages on L2C– and L5–capable satellites in June 2013. The civilian navigation message types will provide improved navigation through the use of the new L2C and L5 civilian frequencies. The German Aerospace Center (DLR) and the University of New Brunswick (UNB) teamed up to collect the CNAV data with five multi–GNSS receivers in the U.S., Canada, South Africa, Singapore, and Australia. The team at DLR and UNB coordinated archive of the data with the CDDIS in support of the IGS MGEX.

Data from the permanent network of 20 GPS monitoring stations maintained by the National Geospatial–Intelligence Agency (NGA) were archived in a special area of the CDDIS for review by select IGS analysis centers. The data span the 2010–2012 time frame. Once review has been completed the data will be archived in the operational

Table 3: GNSS Product Summary

Product Type	Number of ACs/AACs	Volume	Directory
Orbits, clocks, ERP, positions	14+Combinations	1.2 Gb/week	/gnss/products/WWWW (GPS, GPS+GLONASS) /glonass/products/WWWW (GLONASS only)
Troposphere	Combination	2.6 Mb/day, 940 Mb/year	/gnss/products/troposphere/YYYY
Ionosphere	4+Combination	4 Mb/day, 1.5 Gb/year	/gnss/products/ionex/YYYY
Real–time clocks	Combination	6.0 Mb/week	/gnss/products/rtpp/YYYY

(Note: WWWW=4–digit GPS week number; YYYY=4–digit year)

directories.

3.2 IGS Products

The CDDIS routinely archives IGS operational products (daily, rapid, and ultra–rapid orbits and clocks, and weekly ERP and station positions) as well as products generated by IGS working groups and pilot projects (ionosphere, troposphere, real–time clocks). Tab. 3 below summarizes the GNSS products available through the CDDIS. The CDDIS currently provides on–line access through anonymous ftp to all IGS products generated since the start of the IGS Test Campaign in June 1992 in the file system `/gnss/products`; products from GPS+GLONASS products are available through this filesystem. Products derived from GLONASS data only continued to be archived at the CDDIS in a directory structure within the file system `/glonass/products`.

The CDDIS also continues to archive combined troposphere estimates in directories by GPS week. Global ionosphere maps of total electron content (TEC) from the IONEX AACs are archived in subdirectories by year and day of year. Real-time clock comparison products have been archived at the CDDIS in support of the IGS Real-Time Pilot Project since 2009.

3.3 Supporting Information

Daily status files of GNSS data holdings, reflecting timeliness of the data delivered as well as statistics on number of data points, cycle slips, and multipath, continue to be generated by the CDDIS. By accessing these files, the user community can receive a quick look at a day's data availability and quality by viewing a single file. The daily status files are available through the web at URL ftp://cddis.gsfc.nasa.gov/reports/gnss/status. The daily status files are also archived in the daily GNSS data directories.

In preparation for the analysis center's second reprocessing campaign, the CDDIS has developed site–specific reports detailing missing data. Station operators and operational data centers can consult these lists (ftp://cddis.gsfc.nasa.gov/gnss/data/daily/reports/missing) and if available, supply missing files to the CDDIS for inclusion in the global data center archives.

Ancillary information to aid in the use of GNSS data and products are also accessible through the CDDIS. Weekly and yearly summaries of IGS tracking data (daily, hourly, and high–rate) archived at the CDDIS are generated on a routine basis. These summaries are accessible through the web at URL ftp://cddis.gsfc.nasa.gov/pub/reports/gnss. The CDDIS also maintains an archive of and indices to IGS Mail, Report, Station, and other IGS–related messages.

4 System Usage

Fig. 1 summarizes the usage of the CDDIS for the retrieval of GNSS data and products in 2013. This figure illustrates the number and volume of GNSS files retrieved by the user community during 2013, categorized by type (daily, hourly, high–rate, MGEX data, products). Nearly 370 million files (over 50 Tbytes), excluding robot downloads, were transferred in 2013, with an average of nearly 30 million files per month. Fig. 2 illustrates the profile of users accessing the CDDIS IGS archive during 2013. The majority of CDDIS users are from hosts in Europe, Asia, and North America.

5 Recent Developments

In support of the IGS Real–Time Pilot Project (RTPP) and Real–Time IGS Service, the CDDIS has configured a server to provide a real–time streaming capability at GSFC. The CDDIS installed the Ntrip (Networked Transport of RTCM via Internet Protocol) software and successfully tested obtaining product streams from BKG and providing access to streams to authorized users. A module was developed by EOSDIS colleagues to plug into Ntrip that interfaces with an established User Registration System (URS) at NASA GSFC. The module was specifically developed to easily interface with multiple user verification systems and was given back to the community for possible future use. Testing continues on the CDDIS caster installation and the Ntrip user registration module while the CDDIS role in the Real–Time IGS Service is established.

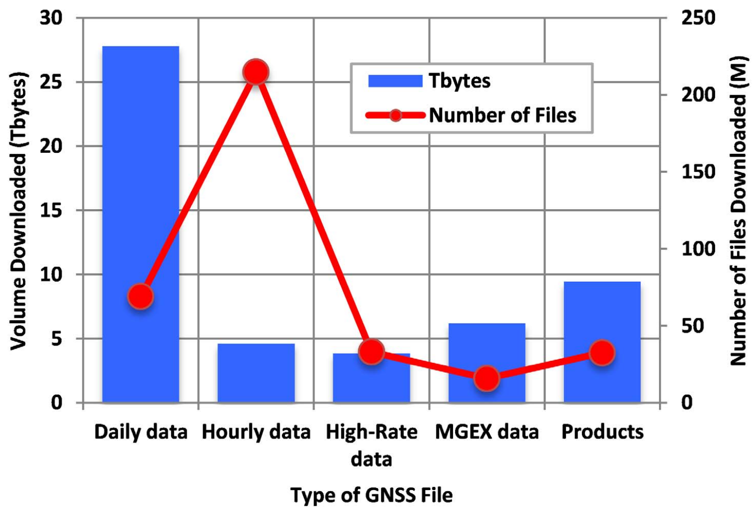

Figure 1: Number and volume of GNSS files transferred from the CDDIS in 2013.

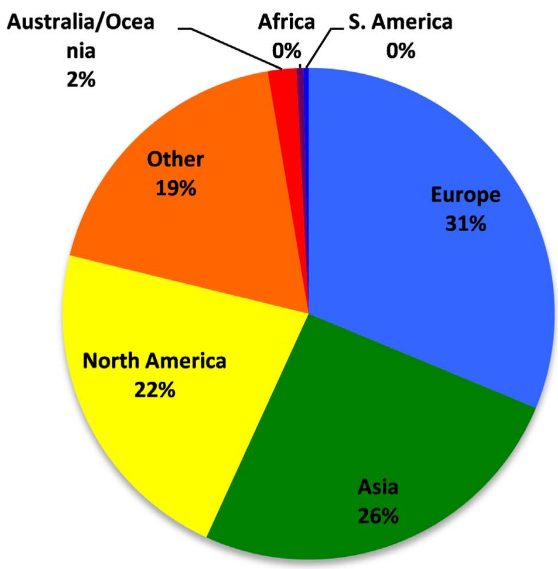

Figure 2: Geographic distribution of IGS users of the CDDIS in 2013.

The CDDIS has recently made modifications to the metadata extracted from incoming data and product files pushed to its archive. These enhancements have facilitated cross discipline data discovery by providing information about CDDIS archive holdings to other data portals such as Earth Observing System (EOS) Clearinghouse (ECHO) and future integration into the Global Geodetic Observing System (GGOS) portal. The staff has begun a metadata evolution effort, re–designing the metadata extracted from incoming data and adding information that will better support EOSDIS applications such as ECHO and the metrics collection effort.

The CDDIS began discussions with the International Council for Science (ICSU) World Data System (WDS) in 2011 to apply for membership. The CDDIS was previously accepted through the ILRS application as a network member. The WDS strives to enable open and long–term access to multidisciplinary scientific data, data services, products and information. The WDS works to ensure long–term stewardship of data and data services to a global scientific user community. In March 2013, the ICSU WDS Scientific Committee accepted the CDDIS application for regular membership. A Letter of Agreement between the CDDIS and ICSU was drafted and signed by C. Noll (on behalf of the CDDIS) and D. Lowe (on behalf of EOSDIS, CDDIS funding organization).

6 Publications

The CDDIS staff attended several conferences during 2013 and presented papers on or conducted demos of their activities within the IGS, including:

Noll, C., M. Dube, N. Pollack, L. Tyahla, and P. Michael. Improvements in Space Geodesy Data Discovery at the CDDIS, Abstract IN31C–1520 presented at *2013 Fall Meeting, AGU*, San Francisco, Calif., 09–13 Dec., 2013.

Electronic versions of this poster and other publications can be accessed through the CDDIS on–line documentation page on the web at URL http://cddis.gsfc.nasa.gov/reports.html.

7 Future Plans

The CDDIS will continue to support the IGS MGEX. The experiment is an excellent opportunity to prepare the data centers for archive of data in RINEX V3. The CDDIS will coordinate with the Data Center Working Group and other IGS data centers to introduce RINEX V3 data into the "operational" GNSS data directory structure, making it easier for users to access these data.

The CDDIS plans to make its real–time caster operational in the coming year as part of the IGS Real–Time Service. Possible future activities in the real–time area include capturing the streams for generation of 15–minute high–rate files for archive at the CDDIS.

In 2013, the IGS analysis centers will begin providing products for the second IGS reprocessing campaign (repro2). The CDDIS will provide support through upload of files from the ACs and online archive of these products (`/gnss/products/WWWW/repro2`).

Work on an update of the CDDIS website began in 2013. In addition to a refresh of the appearance of the website, the content was reviewed and updated. Applications that are under development for data discovery (e.g., a CDDIS implementation of GSAC and a site log browser) will be completed in early 2014 and integrated into the new CDDIS website. The update is planned for completion in early 2014.

The CDDIS has cooperated in the development of Geodetic Seamless Archive Centers (GSAC) with colleagues at UNAVCO, SIO, and the University of Nevada at Reno. The activity provides web services to facilitate data discovery within and across participating archives. The prototype implementation of these GSAC web services at the CDDIS was developed; plans are to incorporate the application in the revised CDDIS website in early 2014.

Funding has been identified in 2014 to procure a system refresh for the CDDIS. The CDDIS system engineer will review current and near–term requirements and develop a hardware procurement strategy.

8 Contact Information

To obtain more information about the CDDIS IGS archive of data and products, contact:

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Part IV

Working Groups, Pilot Projects

IGS Antenna Working Group

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1 Updates and content of the antenna phase center model

Tab. 1 lists 15 updates of the absolute IGS antenna phase center model `igs08_wwww.atx` for 2013. Nine of them are related to changes of the satellite constellation, and four times an update of the model was released, when new receiver antenna calibrations became available. With the update in GPS week 1734, erroneous spikes were removed from the GLONASS calibrations of nearly 50 different receiver antenna types.

In GPS week 1745, the satellite antenna phase center variations (PCVs) of GPS Block II, IIA, IIR–A, IIR–B, IIR–M and IIF were extended with correction values for nadir angles between 15° and 17° provided by CODE (see Fig. 1 and Tab. 2). Those are based on ionosphere–free GPS data of the low Earth orbiter (LEO) missions Jason–2, GRACE–A, GRACE–B, GOCE, and MetOp–A and are mainly relevant for the analysis of LEO data. Further details on all model changes can be found in the corresponding IGSMAILs whose numbers are also given in Tab. 1.

Tab. 3 gives an overview of the data sets contained in the IGS phase center model. The numbers refer to `igs08_1771.atx` that was released in December 2013. For GPS and GLONASS, there are 77 and 89 file entries, respectively. These numbers are bigger than the number of actual satellites, as certain satellites were assigned with different PRN codes or almanac slots, respectively.

During the IGS Workshop 2012 in Olsztyn, it was recommended to adopt conventional phase center offset (PCO) values for Galileo, BeiDou and QZSS. As the update of the ANTEX format w.r.t. manufacturer–defined spacecraft body frames and attitude modes is still pending, the IGS phase center model does still not provide any information on the new GNSS. For the time being, conventional PCO values can be found on the web pages of the IGS Multi–GNSS Experiment (http://www.igs.org/mgex/).

Apart from the satellite antennas, the IGS model meanwhile contains phase center calibration values for 255 different receiver antennas. 84 of them are certain combinations of

Table 1: Updates of the phase center model `igs08_wwww.atx` (`wwww` being the GPS week of the release date) in 2013. Model updates restricted to additional receiver antenna types are only announced via the *IGS Equipment Files* mailing list.

week	date	IGSMAIL	change
1722	07–JAN–13	6711	Added R743 (R08), R801 (R08)
			Decommission date: R712 (R08), R743 (R08), R801 (R26)
1730	05–MAR–13	6743	Added R743 (R08), R801 (R26)
			Decommission date: R801 (R08)
1731	14–MAR–13	—	Added `TRMR10          NONE`
1734	05–APR–13	6753	Spikes removed from GLONASS calibrations of 46 receiver antenna types
1735	12–APR–13	—	Added `TPSCR.G5        TPSH`
			`TRMR4-3         NONE`
			`TRMR6-4         NONE`
			`TRMR8-4         NONE`
			`TRMSPS985       NONE`
1737	26–APR–13	—	Added `ITT3750323      SCIS`
1739	10–MAY–13	6771	Added G049 (G30)
			Decommission date: G035 (G30), G049 (G27)
			Spikes removed from GLONASS calibrations of 2 receiver antenna types
1740	16–MAY–13	6775	Added G066
1745	20–JUN–13	6786	PCVs of GPS Block II/IIA/IIR–A/IIR–B/IIR–M/IIF satellites extended to a maximum nadir angle of 17 degrees
1748	08–JUL–13	6789	Added R747
			Decommission date: R728
			Added `NOV703GGG.R2    NONE`
1755	27–AUG–13	6818	Added G032 (G30)
			Decommission date: G049 (G30)
1758	18–SEP–13	6825	Added G037 (G30)
			Decommission date: G032 (G30)
1764	29–OCT–13	—	Added `CHCX91+S        NONE`
			`LEIICG60        NONE`
			`NOV750.R5       NOVS`
			`TIAPENG2100B    NONE`
			`TIAPENG2100R    NONE`
1769	06–DEC–13	6843	Added G027 (G30)
			Decommission date: G037 (G30)
1771	20–DEC–13	6845	Added G049 (G30)
			Decommission date: G027 (G30)

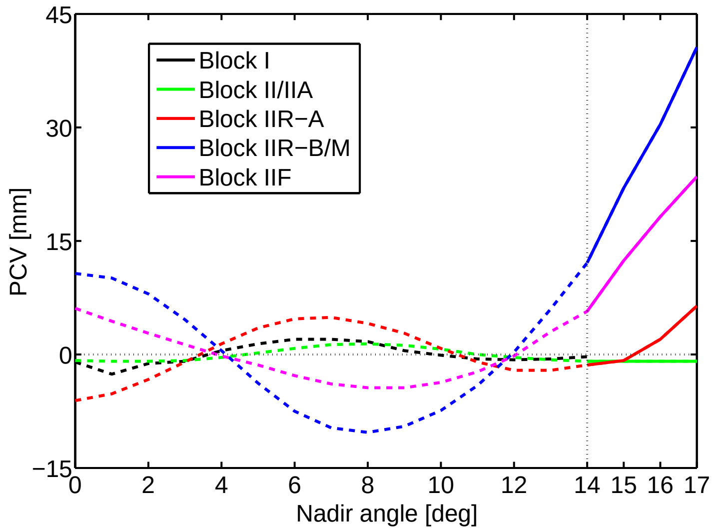

Figure 1: Extension for the GPS satellite antenna PCVs as provided by CODE. PCV values for nadir angles $\leq 14°$ (dashed lines) are identical with the original `igs08.atx` values, whereas those for nadir angles $> 14°$ (solid lines) were derived from LEO data. Block IIA PCVs (green) were extended with constant values and had to be constrained. Block I (black) could not be considered, as all Block I satellites already had been decommissioned when the first GPS–based LEO mission was launched.

Table 2: GPS satellite antenna PCV values [mm] for nadir angles between 14° and 17° in use since GPS week 1745.

Nadir angle	14°	15°	16°	17°
Block I	−0.30	–	–	–
Block II/IIA	−0.90	−0.90	−0.90	−0.90
Block IIR-A	−1.40	−0.80	+2.00	+6.40
Block IIR-B/M	+12.10	+22.00	+30.40	+40.60
Block IIF	+5.70	+12.40	+18.20	+23.50

Table 3: Number of data sets in `igs08_1771.atx` (released in December 2013).

satellite antennas	number	receiver antennas	number
GPS	77	`ROBOT`	119
GLONASS	89	`FIELD`	90
Galileo	0	`COPIED`	32
BeiDou	0	`CONVERTED`	14
QZSS	0		

an antenna and a radome, whereas the remaining 171 antenna types are not covered by a radome. As Tab. 3 shows, `igs08_1771.atx` contains, among others, 119 absolute robot calibrations and 90 converted field calibrations.

As elevation– and azimuth–dependent calibration values down to 0° elevation are mandatory for new or upgraded IGS stations, 154 different antenna types (119 `ROBOT` + 32 `COPIED` + 3 `CONVERTED`) are currently approved for installation. The remaining 101 types are no longer allowed, but their calibration values are still necessary for existing installations (see Section 2) as well as for reprocessing purposes.

2 Calibration status of the IGS network

Tab. 4 shows the percentage of IGS tracking stations with respect to certain calibration types. For this analysis, 437 IGS stations as contained in the file `logsum.txt` (available at ftp://igs.org/igscb/station/general/) on 15 January 2014 were considered. At that time, 103 different antenna/radome combinations were in use within the IGS network. The calibration status of these antenna types was assessed with respect to the phase center model `igs08_1771.atx` that was released in December 2013.

Seven years after the adoption of absolute robot calibrations by the IGS in November 2006, state–of–the–art calibrations comprising elevation– and azimuth–dependent PCVs down to the horizon are available for nearly 80% of all IGS stations. Whereas the portion of stations with phase center corrections derived from relative field calibrations (purely elevation–dependent) hardly changed in recent years, a steady decrease of IGS stations covered by uncalibrated radomes can be noticed.

This decrease results from an upgrade of the equipment at operational stations or from the decommissioning of stations with outdated equipment, but also from an extension of the network with properly calibrated antennas. In order to reach a coverage of 100%, IGS Site Guidelines do not allow converted field calibrations or uncalibrated equipment "at new or upgraded stations".

Table 4: Calibration status of 437 stations in the IGS network (`logsum.txt` of 15 January 2014, `igs08_1771.atx`) compared to former years.

date	absolute calibration (azimuthal corrections down to 0° elevation)	converted field calibration (purely elevation–dependent PCVs above 10° elevation)	uncalibrated radome (or unmodeled antenna subtype)
DEC 2009	61.4%	18.3%	20.2%
MAY 2012	74.6%	8.2%	17.2%
JAN 2013	76.8%	7.7%	15.5%
JAN 2014	**78.7%**	**7.8%**	**13.5%**

Activities of IGS Bias and Calibration Working Group

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1 Introduction

The IGS Bias and Calibration Working Group (BCWG) coordinates research in the field of GNSS bias retrieval and monitoring. It defines rules for appropriate, consistent handling of biases which are crucial for a "model–mixed" GNSS receiver network and satellite constellation, respectively. At present, we consider: P1–C1, P2–C2, and P1–P2 differential code biases (DCB). Potential quarter-cycle biases between different phase observables (specifically L2P and L2C) are another issue to be dealt with. In the face of GPS and GLONASS modernization programs and upcoming GNSS, like the European Galileo and the Chinese BeiDou, an increasing number of types of biases is expected.

The IGS BCWG was established in 2008. More helpful information and related internet links may be found at http://igs.org/projects/bcwg/. For an overview of relevant GNSS biases, the interested reader is referred to (Schaer 2012).

2 Activities in 2013

- Regular generation of P1–C1 bias values for the GPS constellation (based on *indirect* estimation, see Fig. 1) and maintenance of receiver class tables was continued at CODE/AIUB.
- P1–P2 bias values for GPS and GLONASS (see Fig. 2 and Fig. 3.) are a by-product of the ionosphere analysis.
- The tool developed for *direct* estimation of GNSS P1–C1 and P2–C2 DCB values is used to generate corresponding GPS and GLONASS bias results on a regular basis (see Fig. 4, Fig. 5, and Fig. 6). Note that R26, actually representing a 25th active

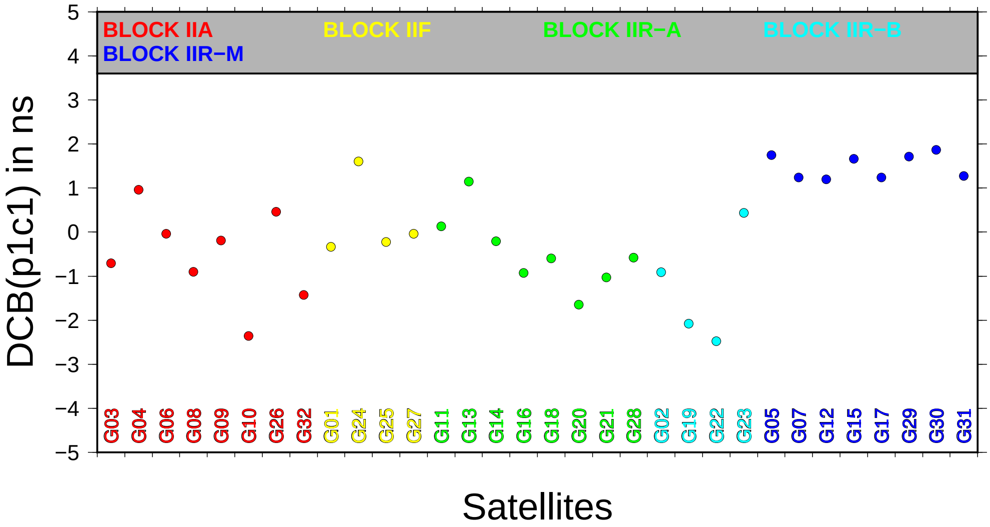

Figure 1: Monthly set of P1–C1 differential code biases for the GPS constellation, for January 2014, computed at CODE.

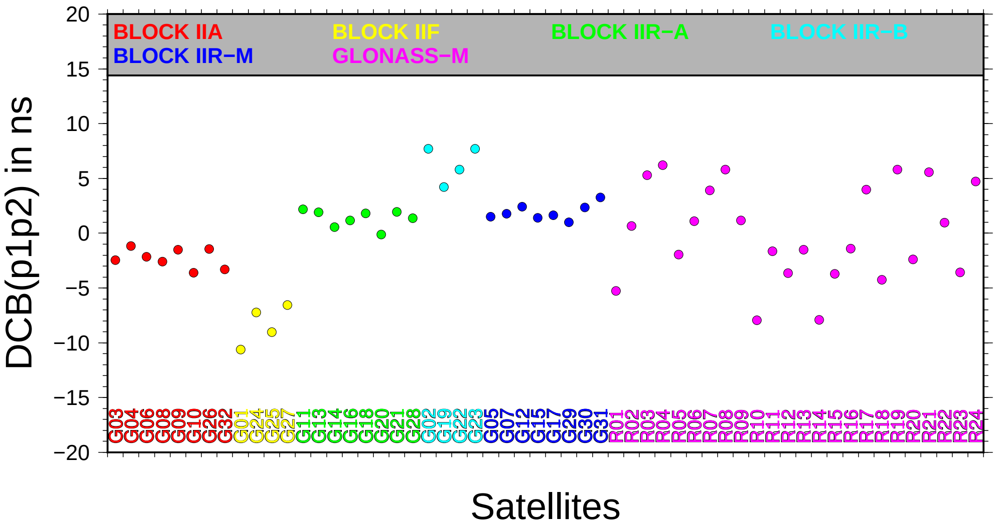

Figure 2: Monthly set of P1–P2 differential code biases for the GPS and GLONASS constellation, for January 2014, computed at CODE.

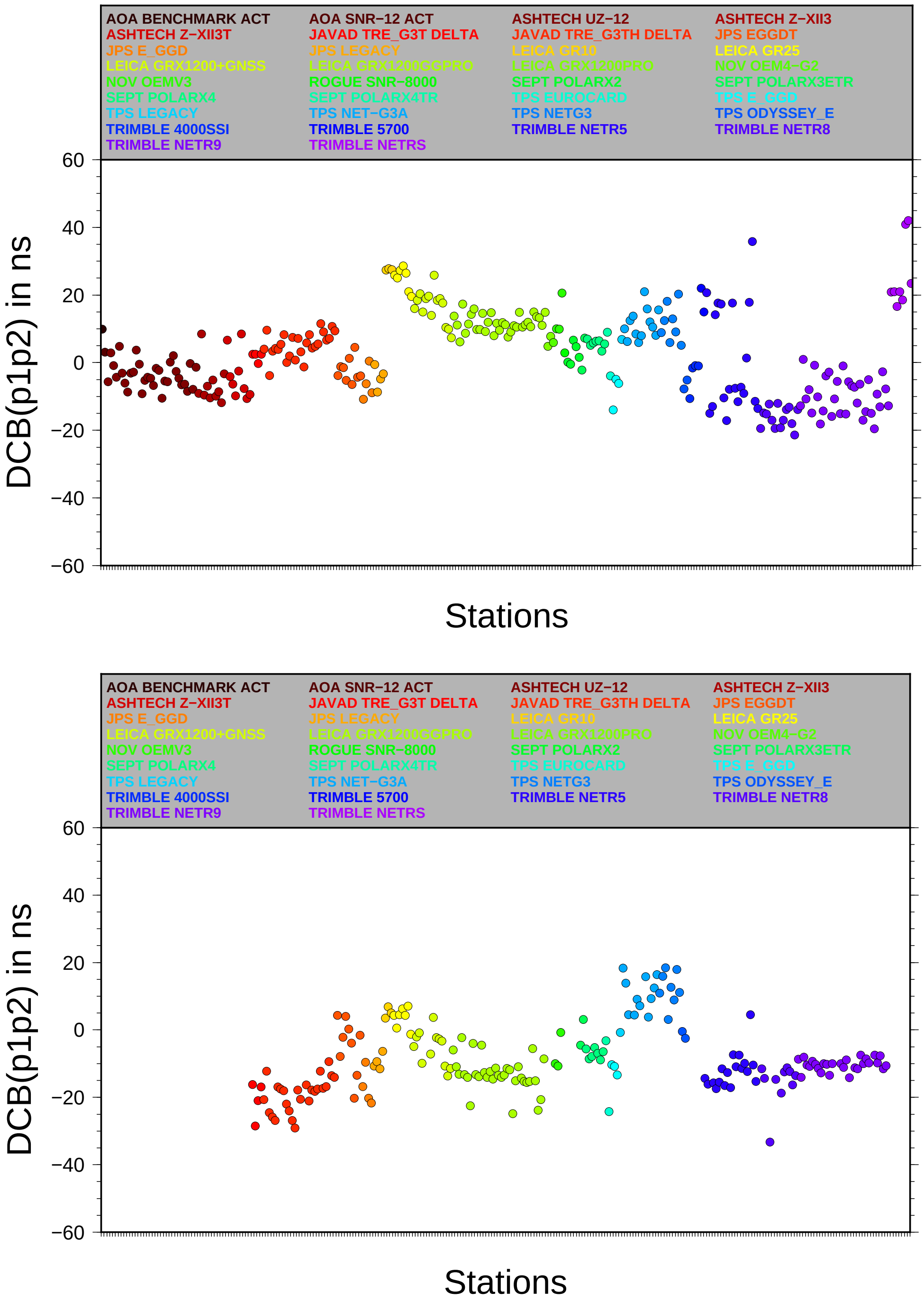

Figure 3: Monthly set of P1–P2 differential code biases for the GPS (top) and GLONASS (bottom) receiver components, for January 2014, computed at CODE.

GLONASS satellite, did already appear in the corresponing P1–C1 bias product (see also IGSMAIL #6581).

- The ambiguity resolution scheme at CODE was extended to GLONASS for three resolution strategies. It is essential that *self-calibrating* ambiguity resolution procedures are used. Resulting GLONASS DCPB(differential code-phase bias) results are collected and archived regularly.
- More experience could be gained concerning station-specific GLONASS-GPS intersystem translation parameters, which are estimated and accumulated as part of CODE's IGS analysis (but completely ignored for all submissions to IGS).
- A key achievement was the activation of a flexible, RINEX3-oriented RINEX observable selection scheme for all CODE analysis lines in August 2013.
- CODE's enhanced RINEX observation data monitoring was continued. Examples may be found at:
  ftp://ftp.unibe.ch/aiub/igsdata/odata2_day.txt
  ftp://ftp.unibe.ch/aiub/igsdata/odata2_receiver.txt
  ftp://ftp.unibe.ch/aiub/igsdata/y2012/odata2_d335.txt
  ftp://ftp.unibe.ch/aiub/igsdata/y2012/odata2_d335_sat.txt
- This RINEX monitoring service was extended to MGEX observation data (available in RINEX3 format). See ftp://ftp.unibe.ch/aiub/mgex/y2013/.

3 Last Reprocessing Activities

In 2012: A complete GPS/GLONASS DCB reprocessing was carried out at CODE on the basis of 1990–2011 RINEX data. The outcome of this P1–C1 and P2–P2 DCB reprocessing effort is: daily sets, a multitude of daily subsets, and in addition monthly sets. Analysis and combination of these remarkably long time series must be seen as a medium-term (or long-term) goal.

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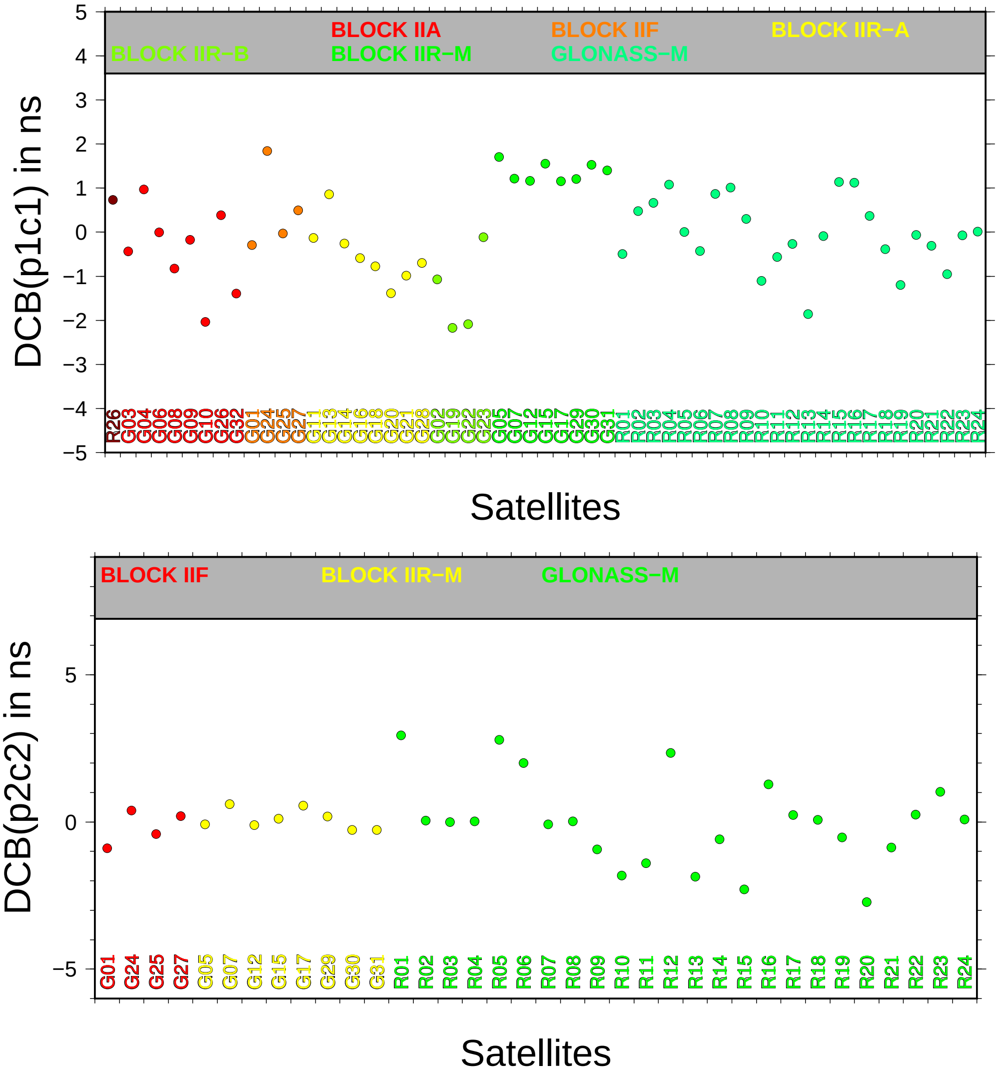

Figure 4: Monthly set of P1–C1 (top) and P2-C2 (bottom) differential code biases for the GPS and GLONASS constellation, for January 2014, computed at CODE.

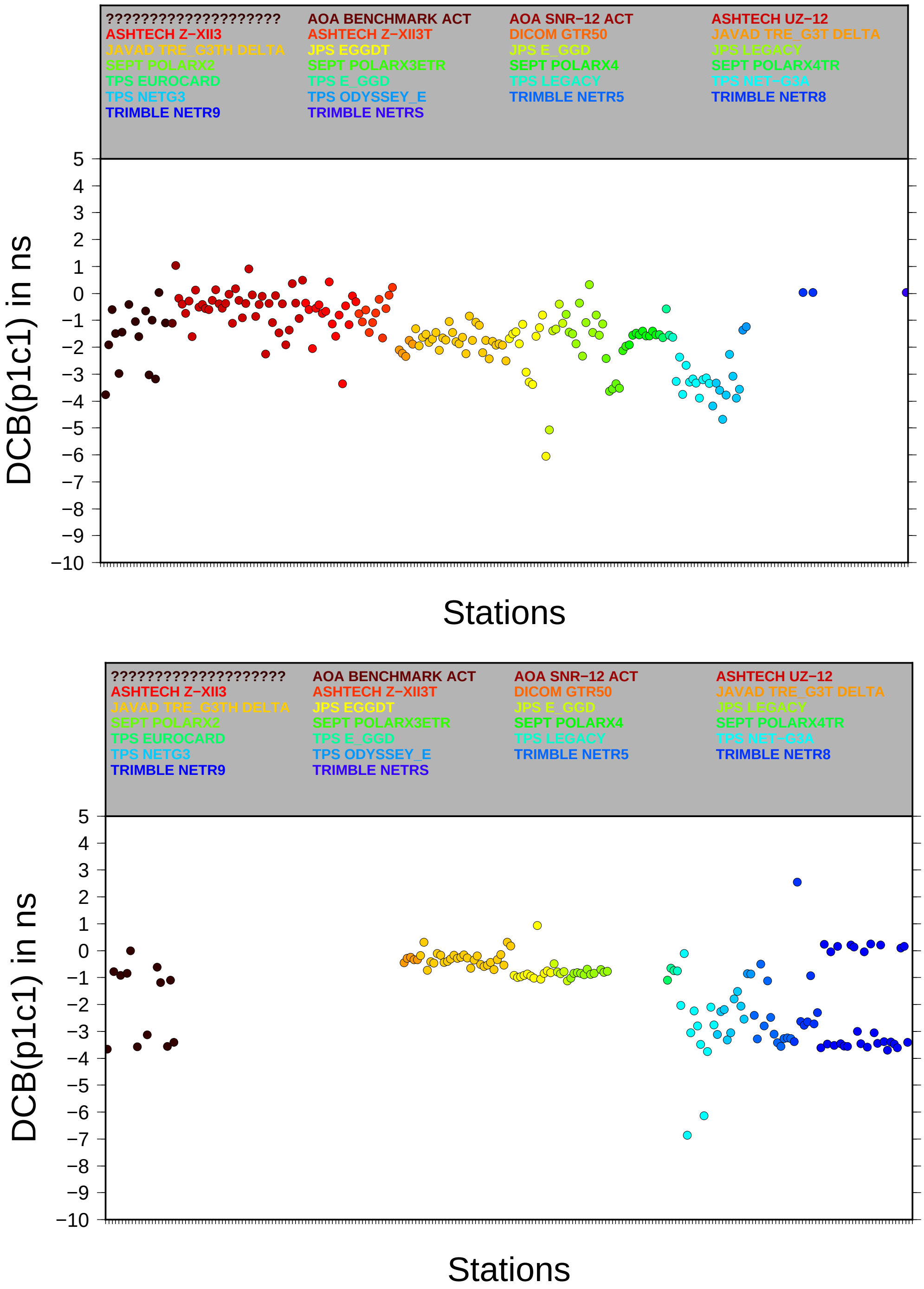

Figure 5: Monthly set of P1–C1 differential code biases for the GPS (top) and GLONASS (bottom) receiver components, for January 2014, computed at CODE.

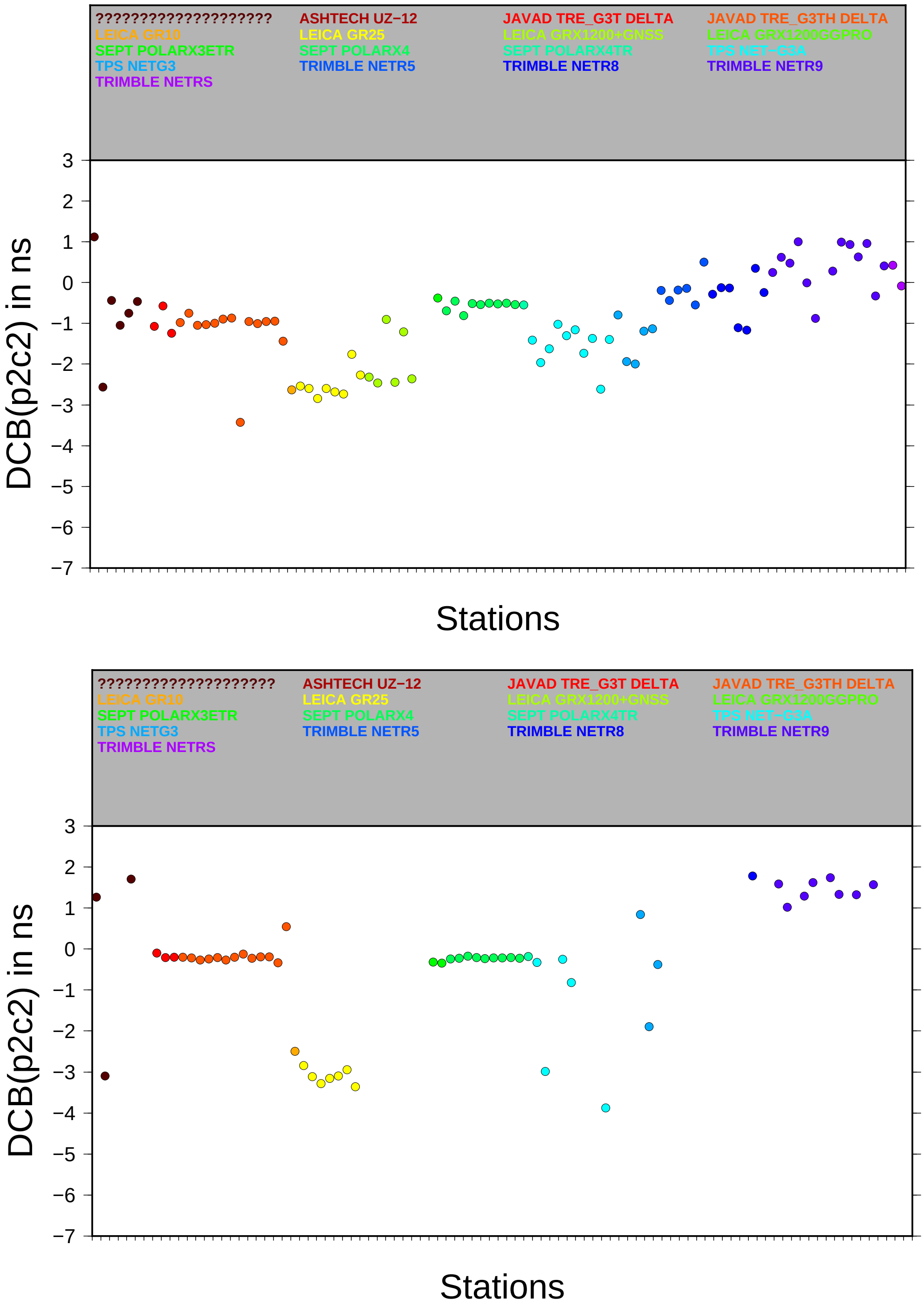

Figure 6: Monthly set of P2–C2 differential code biases for the GPS (top) and GLONASS (bottom) receiver components, for January 2014, computed at CODE.

IGS Data Center Working Group 2013

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1 Introduction

The IGS Data Center Working Group (DCWG) was established in 2002. The DCWG tackles many of the problems facing the IGS data centers as well as develops new ideas to aid users both internal and external to the IGS. The direction of the IGS has changed since its start in 1992 and many new working groups, projects, data sets, and products have been created and incorporated into the service since that time. The DCWG was formed to revisit the requirements of data centers within the IGS and to address issues relevant to effective operation of all IGS data centers, operational, regional, and global.

2 Recent Activities

A Data Center Working Group meeting was held during IGS 2012 Workshop in Olsztyn, Poland. Recommendations where made resulting from presentations during the workshop and from splinter meeting discussions. Major topics discussed were the proposed changes to the RINEX file naming convention, handling multiple releases of files at the data centers, and archiving RINEX V2 and V3 at the data centers.

The Data Center Working Group continues to address these recommendations A new file naming convention to support RINEX V3 data has been proposed but remains in discussion within the RINEX Working Group. Although filename changes directly affect operations, resulting in a significant workload for data centers, a new convention will remove some difficulties DCs have experienced in handling two major versions of RINEX files. For example, the confusion that can be caused by the fact that both RINEX V2 and V3 files currently share the same filename structure.

The DCWG coordinated the directory structure utilized by the data centers in support of the IGS Multi–GNSS Experiment (MGEX). Because of the experimental nature of

MGEX, the data and products are archived in a directory structure separate from the operational directories containing data in RINEX V2 format. At the request of the IGS Infrastructure Committee, all RINEX V3 data available previously at the data centers have been consolidated within the MGEX directory structure thus simplifying access for the user community. Care must be taken, however, by both data suppliers and the data centers to ensure that, until a new RINEX V3 file naming convention is adopted, that RINEX V2 and V3 data remain in separate directories since they utilize the same filename structure.

3 Future Plans

In 2014–2015, the DCWG will continue to work on addressing recommendations from the IGS 2010 and 2012 workshops. Topics the WG hopes to address follow.

- Support of the IGS Infrastructure Committee: A major focus of the DCWG will be to support the IC in its various activities to coordinate the resolution of issues related to the IGS components. These activities will address recommendations from recent IGS Workshops including assessment and monitoring of station performance and data quality, generating metrics on these data.
- Repro2: The DCWG will work with the IGS ACC and coordinate the archival of IGS repro2 products at the IGS Global Data Centers.
- RINEX file naming convention: The DCWG will work with the IC and the RINEX WG on the new IGS RINEX file naming convention.
- Data center harmonization: The working group will consider methodologies for ensuring key data sets are available at all GDCs. Following recommendations from the IGS 2010 Workshop, the WG will coordinate with GDCs to ensure all GDCs archive data from all IGS stations as identified on the IGS network website; ODCs push data, and any subsequent resubmissions, from their stations to ALL GDCs and ODCs issues advisory for ALL resubmissions.
- Compression: As per a recommendation from the IGS 2010 and 2012 workshops, the DCWG will develop a plan for the introduction of a new compression scheme into the IGS infrastructure by evaluating tests of available tools, surveying the IGS infrastructure, making a recommendation on a new IGS compression scheme, and coordinating recommendations with the IC to develop implementation schedule.
- Real–time data streams/high–rate GNSS data handling: IGS data centers must ensure that files generated from these streams are sufficiently reliable. The DCs must also coordinate to ensure consistent copies of high–rate files are archived. This recommendation from 2010 IGS Workshop includes definition and development of 1) tool for comparison of RINEX files from various construction approaches, 2)

minimum requirements for acceptance of an accumulated data stream of observations as a RINEX file in IGS data archives, 3) mandatory/optional observation types to be included, 4) procedures to fill the gaps in the case data streams have been interrupted. This activity should be coordinated with the RTPP, ACs, DCs, and IC. A related recommendation resulted from the 2012 IGS Analysis Workshop stating that until the RINEX V3 filenaming convention is finalized, separate directories for distinguishing between files created from streams and by receivers will be established by all DCs.

- Next meeting: A meeting of the DCWG is planned for the 2014 IGS Workshop in July 2014.

4 Membership

- Carey Noll (NASA GSFC/USA), Chair
- Yehuda Bock (SIO/USA)
- Ludwig Combrinck (HRAO/South Africa)
- Bruno Garayt (IGN/France)
- Jake Griffiths (NOAA/USA), ex–officio
- Heinz Habrich (BKG/Germany)
- Michael Moore (GA/Australia) (tbc)
- Ruth Neilan (JPL/USA), ex–officio
- Markus Ramatschi (GFZ/Germany)
- Jim Ray (NOAA/USA)
- Nacho.Romero (ESA/Germany)
- Mike Schmidt (NRCan/Canada)
- Giovanni Sella (NOAA/USA)
- Grigory Steblov (RDAAC/Russia)
- Dave Stowers (JPL/USA)

IGS Ionosphere Working Group Technical Report 2013

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Geodynamics Research Laboratory
University of Warmia and Mazury(GRL/UWM)
in Olsztyn, Poland

1 General goals

The Ionosphere Working group started the routine generation of the combine Ionosphere Vertical Total Electron Content (TEC) maps in June 1998. This has been the main activity so far performed by the four IGS Ionosphere Associate Analysis Centers (IAACs): CODE (Center for Orbit Determination in Europe, Astronomical Institute, University of Berne, Switzerland), ESOC (European Space Operations Center of ESA, Darmstadt, Germany), JPL (Jet Propulsion Laboratory, Pasadena, California, U.S.A), and UPC (Technical University of Catalonia, Barcelona, Spain). Independent computation of rapid and final VTEC maps is used by the each analysis centers: Each IAACs compute the rapid and final TEC maps independently and with different approaches including the additional usage of GLONASS data in the case of CODE.

2 Membership

Dieter Bilitza	GSFC/NASA
M. Codrescu	SEC
Patricia H. Doherty	BC
Joachim Feltens	ESA/ESOC
Alberto Garcia–Rigo	UPC
Pierre Heroux	NRCAN
Attila Komjathy	JPL
Richard B. Langley	UNB
Maria Lorenzo	ESA/ESOC
Raul Orus	UPC
Ola Ovstedal	UMB
Jaime Fernandez Sanchez	ESA/ESOC
Javier Tegedor	ESA/ESOC
Robert Weber	TU Wien
Brian Wilson	JPL
Mahdi Alizadeh	TU Vienna
Ljiljana R. Cander	RAL
Anthea Coster	MIT
John Dow	ESA/ESOC
Mariusz Figurski	MUT
Manuel Hernandez–Pajares	UPC
Norbert Jakowski	DLR
Andrzej Krankowski	UWM
Reinhard Leitinger	TU Graz
A. Moore	JPL
Michiel Otten	ESA/ESOC
Ignacio Romero	ESA/ESOC
Schaer Stefan	CODE
Rene Warnant	ROB
Pawel Wielgosz	UWM
Michael Schmidt	DGFI

3 Products

a) final GIM (please note that GIMs also include GPS and GLONASS stations' and satellites' DCBs)

- combination of CODE, ESA, JPL and UPC iono products conducted by UWM
- temporal and spatial resolution – at $2^{hr}\times5°\times2.5°$ (UT×Lon.×Lat.)
- availability with a latency of 11 days

b) rapid GIM

- combination of CODE, ESA, JPL and UPC iono products conducted by UWM
- temporal and spatial resolution – at $2^{hr}\times5°\times2.5°$ (UT× Lon.×Lat.)
- availability with a latency of less than 24 hours

c) predicted GIM for 1 and 2 days ahead (pilot product)

- combination of ESA and UPC iono products conducted by ESA
- temporal and spatial resolution – at $2^{hr}\times5°\times2.5°$ (UT× Lon.×Lat.)

4 Key accomplishments

a) IGS Global ionosphere predicted products for 1 and 2 days ahead (pilot product). This new IGS products are currently based on predicted ionosphere maps prepared by UPC and ESA.

b) IGS Global ionosphere maps with 1 hour and 15 min. time resolution (pilot products). This new IGS products are currently based on ionosphere maps prepared by UPC and ESA.

c) IGS Global Ionosphere Maps (GIMs) now include differential code biases (DCBs) for GLONASS satellites.

d) The pilot phase of the new IGS ionospheric product – TEC fluctuations maps

5 The pilot phase of the new IGS ionospheric product – TEC fluctuations maps

It is known that GNSS radio signals passing through the ionosphere suffer varying degrees of rapid variations of their amplitude and phase – signal fluctuations, referred as scintillations, are created by random fluctuations of the medium's refractive index, which are caused by inhomogeneities inside the ionosphere. These effects are caused by the presence of a wide range of scale size irregularities in the ionosphere.

Currently, there is a high demand to increase the precision and reliability of GNSS positioning. The spatial and temporary dynamics of the ionosphere fluctuations depends on geophysical conditions, and knowledge of this is very important, especially during space weather events. For this reason several approaches to analyze the ionospheric total electron content (TEC) fluctuations effects on GNSS signals have been carried out.

The ionospheric fluctuations service for the Northern hemisphere mid–latitudes and sub–auroral regions is strongly actual as a lot of GNSS precise positioning users are located in this area. The IGS service, illustrated the variability of the TEC fluctuations, was presented in 2012 and developed in 2013.

According to the resolution of the IGS Ionosphere Working Group, which has been passed during the IGS Workshop 2012 in Olsztyn, the new product – the ionospheric fluctuations maps – was established as a pilot project of the IGS service.

Taking into account that the Earth ionosphere is formed by superimposing of Earth magnetic field and Solar irradiance level for the geomagnetic field the TEC fluctuations are calculated as a function of a spherical geomagnetic latitude and magnetic local time.

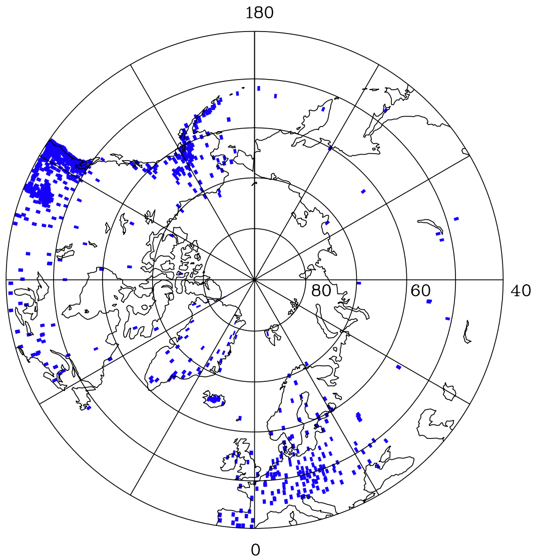

Figure 1: The locations of the stations around the North Geomagnetic Pole.

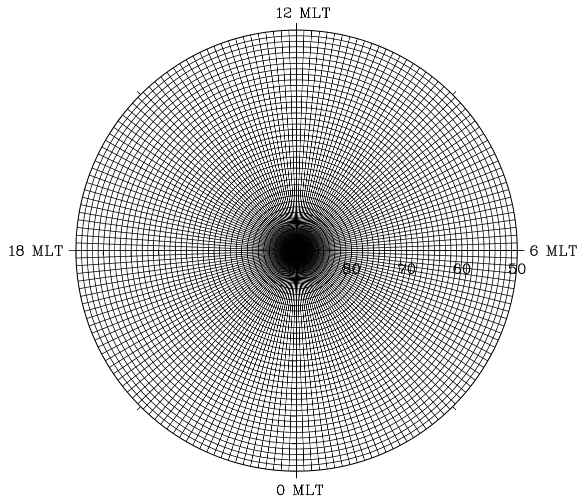

Figure 2: The grid of ROTI maps in polar coordinates with grid 2 degree (magnetic local time) and 2 degree (geomagnetic latitude).

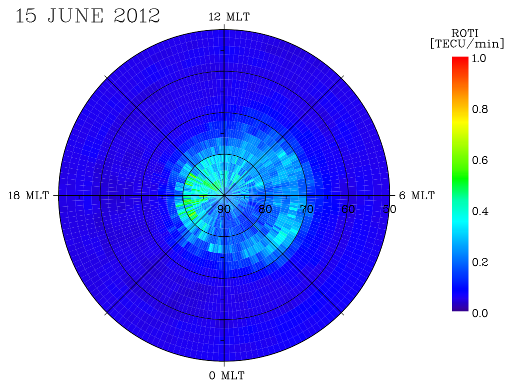

Figure 3: The example of ROTI map for the geomagnetic quiet day.

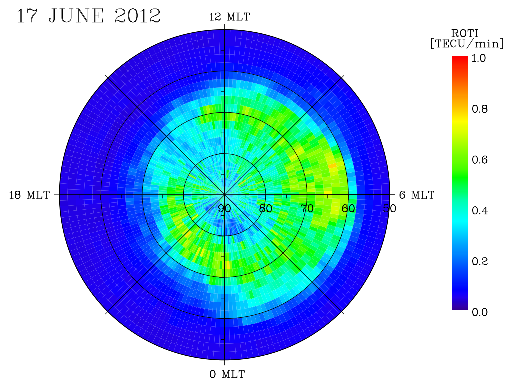

Figure 4: The example of ROTI map for the geomagnetic disturbed day.

In the updated version, more than 700 permanent stations (available both from UNAVCO and EUREF databases) have been involved into analysis of the ionosphere fluctuation service. In order to describe the TEC variability in the ionosphere, the Rate of TEC (ROT) and its deviation – Rate of TEC Index (ROTI) are used. The ROT is calculated as the difference of two geometry–free observations for consecutive epochs. The ROTI represents the ROT deviation over 5 minute periods with one minute resolution. This ionospheric fluctuations service allows to estimate the levels of TEC fluctuations for spatial range from 50 degree of the north geomagnetic latitude to the North Geomagnetic Pole. The results have visualization as daily ROTI maps in polar coordinates with grid 2 degree (magnetic local time) and 2 degree (geomagnetic latitude). The every grid cell represents the average weighted value of ROTI values included in this cell.

The final TEC fluctuations maps are written in the modified IONEX format. During the pilot phase the graphical form of the products can be found at: http://igsiono.uwm.edu.pl.

6 Publications 2012–2013

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7 Plan for activities in 2014:

The following actions to be considered:

- Higher temporal resolution of IGS GIMs – 1 hour and less, combination conducted by UWM to be started as official/routine product.
- Predicted IGS GIMs – 1 and 2 days ahead, combination conducted by UWM to be started as official/routine product.

- Starting a new official/operational product – TEC fluctuation changes over North Pole to study the dynamic of oval irregularities (carried out by UWM to be started as official/routine product after performance evaluation period.
- The new the IAAC from GNSS Research Center (GRC), Wuhan University, China.
- Cooperation with IRI COSPAR group

Future improvements are determined by users' requirements (number of users has significantly increased during the last 15 years).

Multi–GNSS Working Group

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1 Introduction

The Multi–GNSS Working Group (MGWG) has been established by the IGS to build up experience in the use of new satellite navigation systems and modernized signals. As part of this task, the MGWG coordinates the performance of the Multi–GNSS Experiment (MGEX) which comprises the build–up of a new network of sensor stations, the characterization of the user equipment and space segment, the development of new concepts and data processing tools, and, finally, the generation of early data products (Rizos et al. (2013), Montenbruck et al. (2013b), (2013d)). MGEX is considered as a preparatory step for a future multi–GNSS pilot service that will integrate the new constellations into the established IGS product and service portfolio. A list of current MGWG members and their respective contributions is given in Tab. 1.

2 Network

Since the beginning of 2013, the MGEX network has grown substantially and now includes roughly 90 stations (Dec. 2013; Fig. 1). A large number of new stations have been made available by DLR (CONGO) and ESA. In addition, CNES has added multiple new stations of their REGINA network that are of particular value in view of their remote location. The network now provides good global coverage for Galileo tracking. QZSS and regional+global BeiDou tracking is also supported, but more stations tracking these systems are still desired to improve tracking coverage and geometry. Incorporation of Australia/Pacifica stations from Geoscience Australia is presently delayed due to lacking manpower and pending technical constraints (RINEX generation, compatibility of R/T formats with BKG infrastructure). Further efforts will also be required to acquire new stations supporting the Indian Regional Navigation Satellite System (IRNSS).

Table 1: Multi–GNSS Working Group members and task areas (status Dec. 2013)

Name	Institution	Task areas
Rolf Dach	AIUB	Orbit and clock products, SP3 format extension (SP3d)
Jan Dousa	GOPE	Quality control
Ahmed El–Mowafy	CUT	Quality control
Heinz Habrich	BKG	Data archives
Satoshi Kogure	JAXA	Orbit and clock products, QZSS mission interface
Richard Langley	UNB	Public outreach, GNSS constellation monitoring
Huiciu (Yolanda) Liu	BACC	Quality control
Hans v.d. Marel	TUD	System characterization
Oliver Montenbruck	DLR/GSOC	Chair MGWG, MGEX coordination, network, DCB product,data and product analysis (BeiDou, Galileo, QZSS, IRNSS)
Felix Perosanz	CNES	Orbit and clock products
Chris Rizos	UNSW	External representation (ICG, IGMA,...)
Tim Springer	ESOC	Data processing strategies
Rene Warnant	ULG	Ionosphere
Peter Steigenberger	TUM/IAPG	Orbit and clock products, broadcast ephemeris product
Maik Uhlemann	GFZ	Orbit and clock products

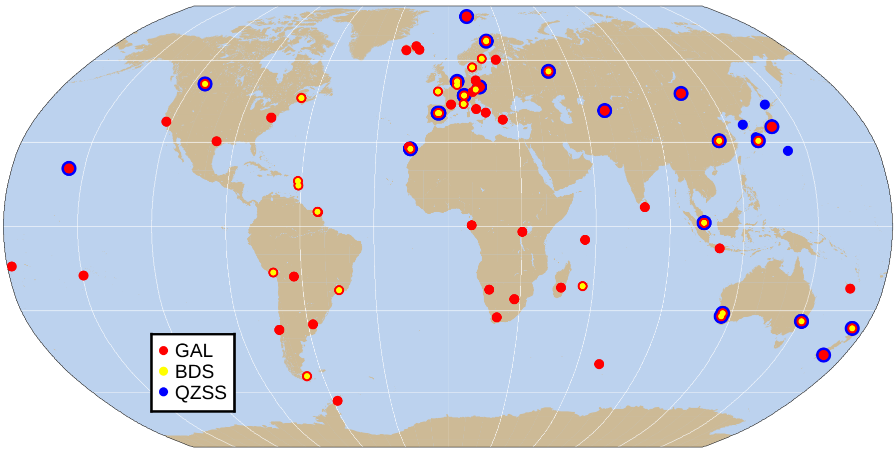

Figure 1: Distribution of MGEX stations supporting tracking of QZSS (blue), Galileo (red), and BeiDou (yellow) as of Dec. 2013.

The MGEX network offers a large fraction of real–time stations and is thus well prepared to incorporate new constellations into real–time precise–point–positioning services. Real–time data streams from all supporting stations are publicly made available at the MGEX caster hosted by BKG (http://mgex.igs-ip.net/). For ease of use, the vendor–specific data formats received from individual stations are translated into the new RTCM 3.2 format (RTCM 2013), which offers a standardized framework for real–time transfer of multi–GNSS observation and ephemeris data and enables a consistent conversion to offline RINEX data.

While MGEX collects a huge amount of data, numerous problems (e.g. suspicious/wrong observation types, inconsistent RINEX file headers, wrong PRNs, bad data, inconsistent/wrong broadcast ephemeris parameters) exist, which affect the practical use of those data. No systematic data screening and quality control (QC) has been performed so far and no dedicated infrastructure is available. To cope with this issue a "quality control task force" has been established within the MGWG in late 2013. It will review QC tools (Anubis, BQC, BNC) and concepts independently developed at GOPE (Vaclavovic and Dousa 2013a), (2013b)), BACC, BKG and CUT (El-Mowafy (2013a), (2013b)) with the final goal of setting up a QC environment for the MGEX network and performing systematic QC of past and new MGEX observation data.

3 Products

Precise orbit and clock products of new GNSSs are contributed by various MGEX analysis centers including AIUB, CNES/CLS, GFZ, JAXA, TUM, and, most recently, ESA. While some of these products are only available for limited test periods, products for Galileo and QZSS are routinely provided by at least two MGEX analysis centers. The cross–comparison and satellite laser ranging validation indicate a very encouraging performance (with accuracies at the few decimeter level) but provides evidence of systematic errors (Hackel et al. (2013), Montenbruck et al. (2013d), (2013e), Prange et al. (2013a), (2013b), (2013c); Steigenberger et al. (2013b), (2013c)) that are most likely related to solar radiation pressure modeling issues. In case of Galileo, initial performance improvements have been demonstrated through use of a box–wing solar radiation model, but further research will be required to approach the accuracy level currently achieved for GPS and GLONASS. Also, efforts need to be made to properly consider the constellation–specific attitude modes in common GNSS orbit determination software packages.

So far, no BeiDou precise orbit and clock products are made available by any IGS or non–IGS institution but a combined multi–GNSS broadcast ephemeris is offered as part of the MGEX project. While limited in accuracy, this product can still be used for a wide range of basic applications and serves as a substitute until precise products will be contributed for all GNSSs.

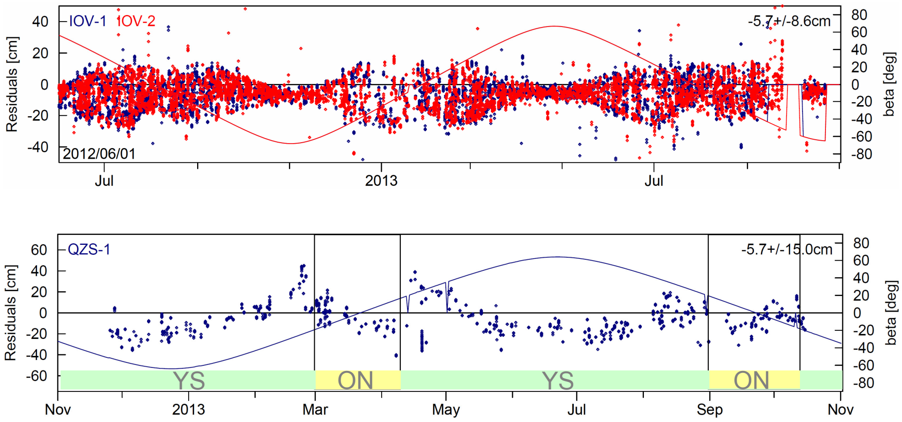

Figure 2: Satellite laser ranging residuals of Galileo–IOV (top) and QZSS (bottom) orbit products (Montenbruck et al. 2013e). Notable variations of the orbit quality with the Sun–angle above the orbital plane (β–angle) can be recognized for both systems. For QZSS, differences between orbit normal mode (ON) and yaw–steering mode (YS) can, furthermore, be noted.

4 Biases

GNSS observations are affected by group and phase delays in the space and user segments, which need to be properly characterized to fully exploit their inherent precision. In the context of modernized and emerging navigation systems the multiplicity of signals causes a major challenge for a consistent processing of GNSS observations (Montenbruck and Hauschild 2013). Various efforts have therefore been made to characterize inter–signal, inter–frequency and inter–system biases within the MGEX project(Odijk and Teunissen (2013a), (2013b), Montenbruck et al. (2014), Springer et al. (2013)). The routine generation of a GPS, Galileo and BeiDou product for differential code biases (DCBs) is foreseen for early 2014.

By way of example, Fig. 3 illustrates differential code biases of the Galileo–IOV satellites for E1 and E5a signals as derived from MGEX observations and compares those to values obtained by the Galileo control segment.

5 GNSS Evolution

Within the MGEX context, a variety of individual system studies have been performed for characterization of new navigation systems such as BeiDou (Montenbruck and Steigenberger 2013), Montenbruck et al. (2013a)) and IRNSS (Langley et al. (2013), Thoelert et al. (2013)). Satellite launches and constellation changes have routinely been monitored and compiled(Langley (2013a), (2013b), (2013c), Montenbruck and Langley (2013)).

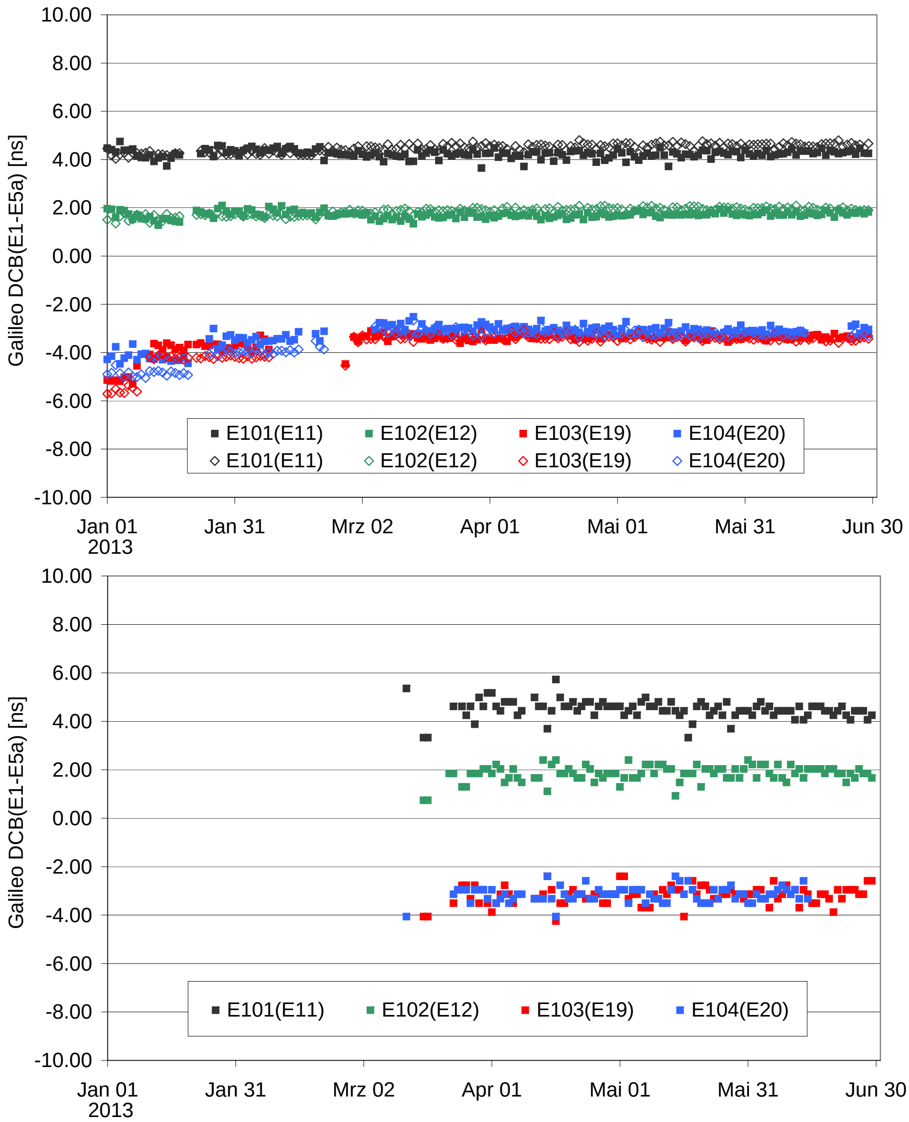

Figure 3: Galileo E1–E5a differential code biases of Galileo IOV satellites (top) for pilot–only tracking (solid squares), and combined pilot–data tracking (open diamonds) as compared to DCBs from BGD_{E5aE1} Broadcast Group Delay parameters transmitted in the Galileo navigation message (bottom) for the first half of 2013 (from Montenbruck et al. (2014)).

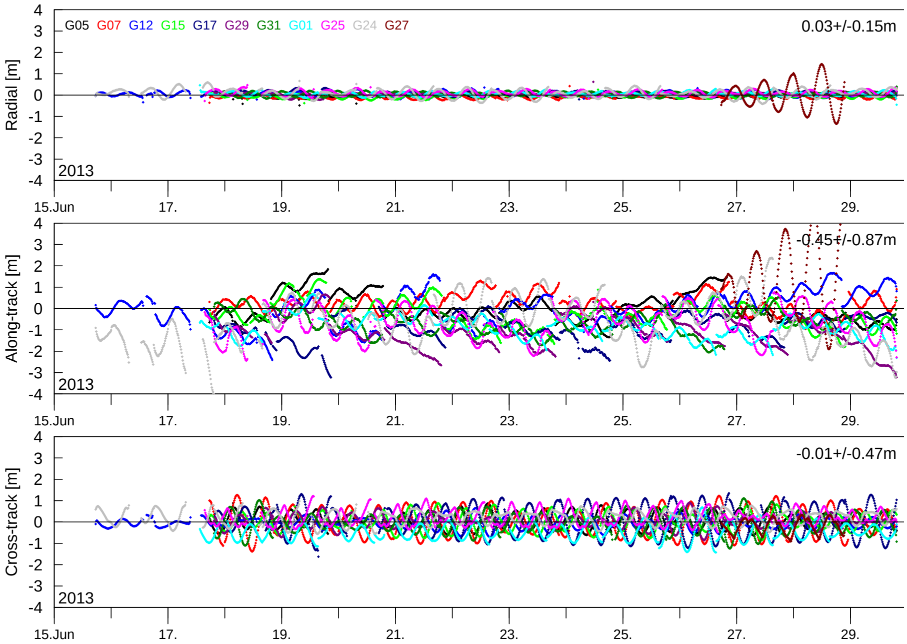

Figure 4: Accuracy of GPS CNAV broadcast ephemeris data transmitted during the June 2013 test campaign relative to IGS precise orbit products.

In June 2013 the first GPS CNAV test campaign has been supported by the Multi–GNSS Working Group (Montenbruck et al. 2013c). Test data have been collected with a selected set of global DLR and UNB stations. The data were decoded, analyzed and made publicly available through CDDIS for interested users. CNAV includes novel information such as Earth orientation parameters and inter–signal group delay corrections. The comparison with precise IGS orbits (Fig. 4) furthermore exhibits an improved smoothness and reduced discontinuities of CNAV broadcast orbits, even though the overall accuracy is presently still similar to that of the legacy navigation message (LNAV).

6 Standardization

The Multi–GNSS WG has contributed to further evolve the RINEX3 and RTCM3 standards for multi–GNSS use and to extend the SP3 format (version “SP3d” proposal for >85 satellites) in close interaction with other IGS working groups.

7 Public Outreach

The MGEX website (http://igs.org/mgex) continues to serve as a primary portal for MGEX related information and access to the MGEX data repository. During the reporting period regular updates have been performed in an effort to provide up-to–date information on GNSS constellations as well as MGEX data and products. In view of access restrictions for Chinese users, a mirror site (http://igsws.unavco.org/mgex/) has been implemented by UNAVCO.

Achievements of the MGEX project have been advertised in various overview papers and magazine articles (Rizos et al. (2013), Montenbruck et al. (2013b),(2013d)) as well as numerous conference and workshop presentations (including CSNC, Wuhan; EGU, Vienna; ENC, Vienna: EUREF Symp. Budapest; HxGN LIVE Conf., Las Vegas; Joint Int. Symp. on Deformation Monitoring, Nottingham; National GPS/GNSS Symposium, Tokyo; Int. Symp. on GNSS Istanbul; SBAS Iono Meeting, Bath) given by individual members of the Multi–GNSS Working Group.

Acronyms and Abbreviations

AIUB	Astronomisches Institut der Unversität Bern
BACC	Beijing Aerospace Control Center
BKG	Bundesamt für Kartographie und Geodäsie
CLS	Collecte Localisation Satellites
CNES	Centre National d'Etudes Spatiales
CONGO	Cooperative Network for GNSS Observation
CUT	Curtun University of Technology
DLR	Deutsches Zentrum für Luft– und Raumfahrt
ESA	European Space Agency
ESOC	European Sapce Operations Center
GFZ	Deutsches GeoForschungsZentrum
GOPE	Geodetic Observatory Pecný
IAPG	Institute of Astronomical and Physical Geodesy
JAXA	Japan Aerospace Exploration Agency
MGM–net	Multi–GNSS Monitoring Network
REGINA	REseau GNSS pour l'IGS et la Navigation
RTCM	Radio Technical Commission for Maritime Services
TUD	TU Delft
TUM	Technische Universität München
ULG	Université de Liège
UNB	University of New Brunswick
UNSW	Univesity of New South Wales

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IGS Reference Frame Working Group Coordinator Report 2013

P. Rebischung[1], *B. Garayt*[2], *X. Collilieux*[1], *and Z. Altamimi*[1]

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[2] IGN SGN

1 Introduction

The Reference Frame Working Group (RFWG) activities were not marked by any major event in 2013. The two next sections will therefore simply give a brief overview of the recent IGS SINEX combination results and review the current status of the IGb08 Reference Frame. Section 4 finally summarizes the RFWG recommendations to the IGS Analysis Centers in view of the 2$^{\text{nd}}$ IGS reprocessing campaign.

2 Recent IGS SINEX combination results

Fig. 1 shows the RMS of the Analysis Center (AC) station position residuals from the daily IGS SINEX combinations of year 2013, i.e. the global level of agreement between the AC and IGS combined station positions once reference frame differences have been removed. Except for SIO, which has been excluded from the IGS combinations since GPS week 1709, the AC station position residuals have remained at fairly stable levels over 2013. The overall agreement between the daily terrestrial frames of the leading ACs is now at the level of 1 mm for horizontal station positions and 3 mm for station heights. A comparative study of the AC station position time series since the switch to daily SINEX integrations (Ray et al. 2013) nevertheless revealed several short–period AC–dependent features.

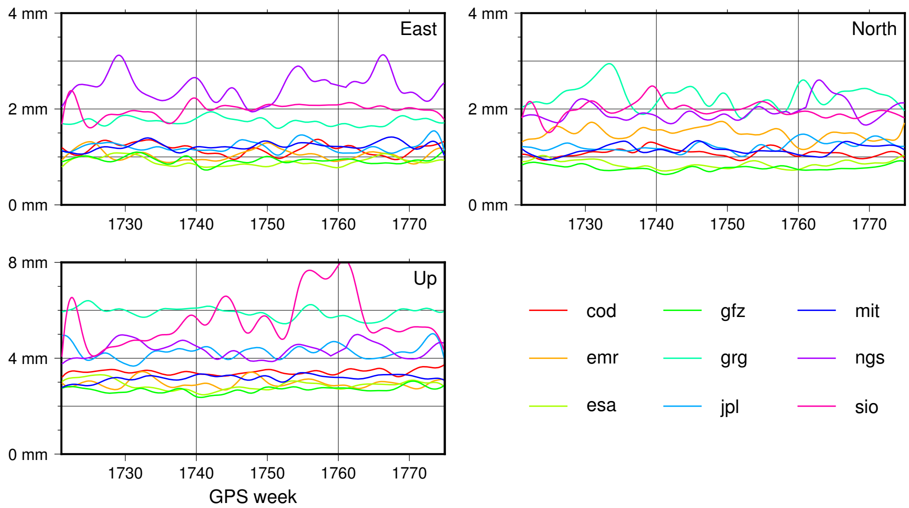

Figure 1: RMS of AC station position residuals from the 2013 daily IGS SINEX combinations. All time series were low–pass filtered with a 10 cycles per year cut–off frequency.

Fig. 2 and 3 show the AC Earth Orientation Parameter (EOP) residuals from the IGS SINEX combinations of year 2013. With a few noticeable exceptions (NGS for pole coordinates; MIT for the Length of Day – LOD), the AC EOP residuals show rather homogeneous high–frequency scatters. Several problematic features can however be noticed in specific AC EOP estimates:

- Because of unexpectedly small formal errors, the MIT LOD estimates have overwhelmed the IGS combined LODs since GPS week 1726. The disproportion of the MIT LOD formal errors remains unexplained yet.

- Pronounced sub–seasonal and abrupt variations can be noticed in the COD X–pole and Y–pole rate estimates. There are indications that these excursions, as well as smaller features in the ESA and GFZ Y–pole rate estimates, are caused by GLONASS orbit modeling problems (T. Springer, personal communication).
- Comparable excursions are visible in the EMR X–pole and pole rate estimates, but remain unexplained. (EMR does not make use of GLONASS data.) Due to especially large offsets, the EMR pole rate estimates were thus rejected from the IGS combinations of weeks 1760–1762.

3 Status of the IGb08 Reference Frame

Fig. 4 illustrates the progressive decay of the IGS08/IGb08 Reference Frames (RF) since the adoption of IGS08 on GPS week 1632 (April 17, 2011; IGSMAIL #6354). The abrupt

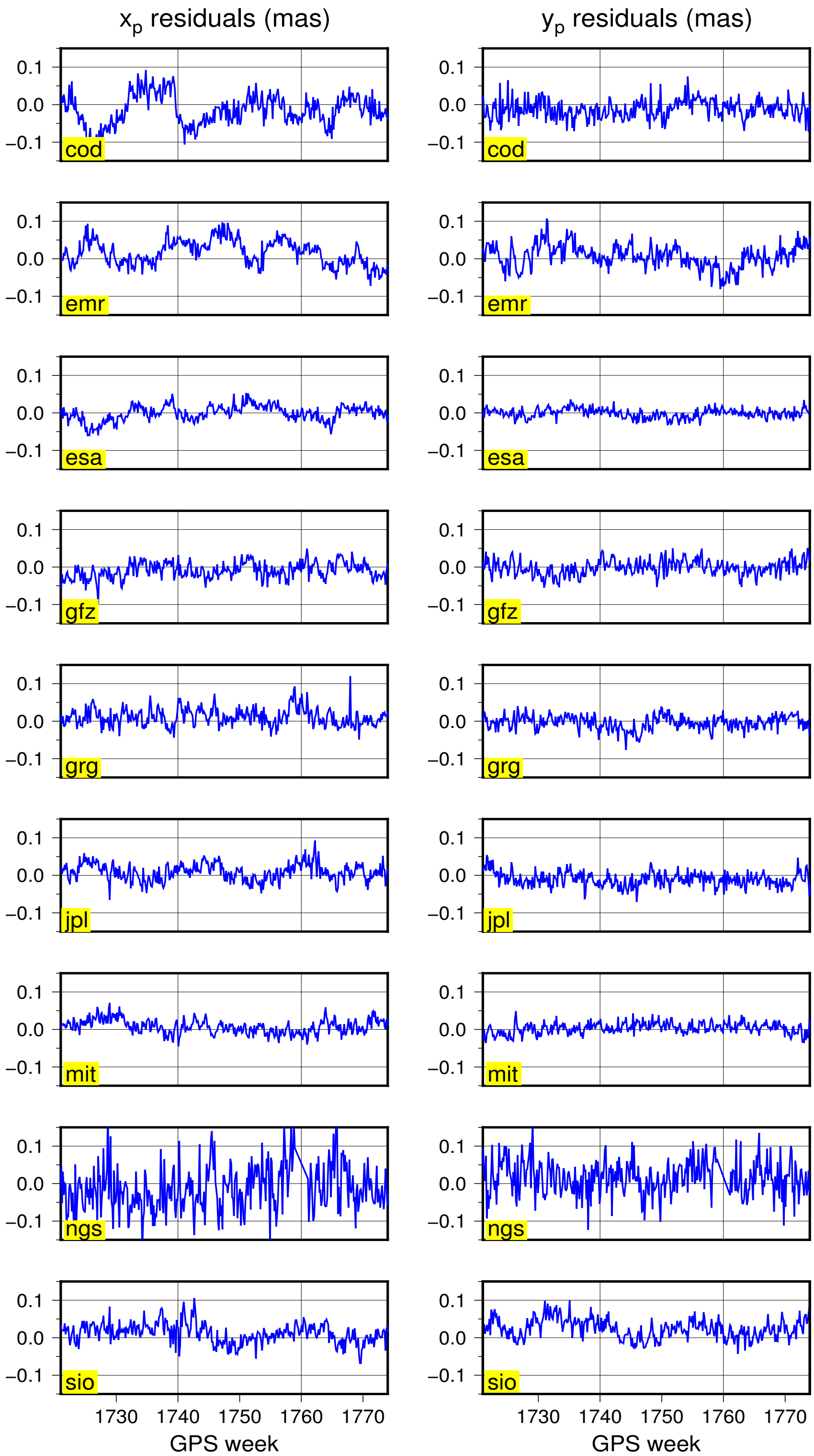

Figure 2: AC pole coordinate residuals from the 2013 daily IGS SINEX combinations.

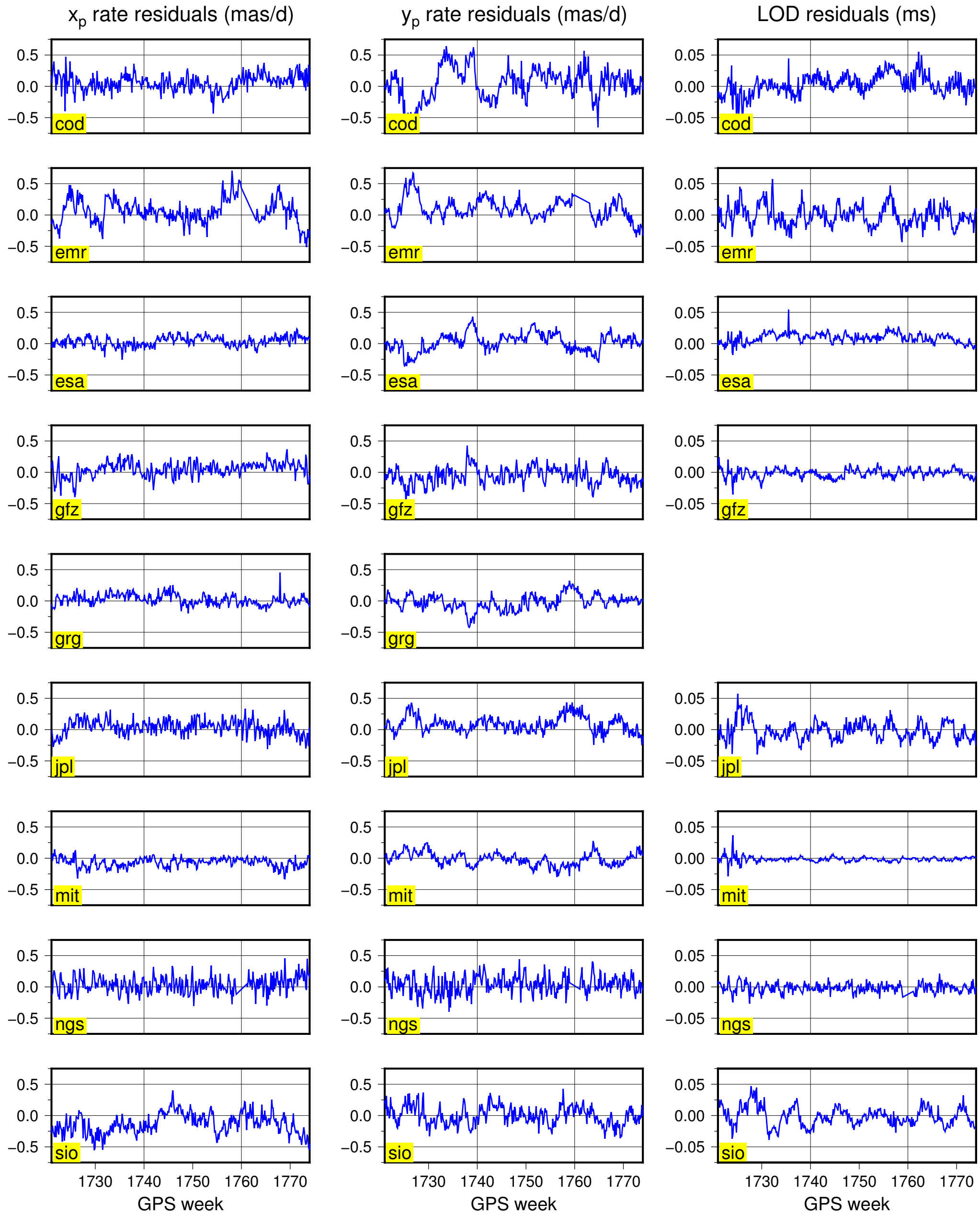

Figure 3: AC pole rate and LOD residuals from the 2013 daily IGS SINEX combinations.

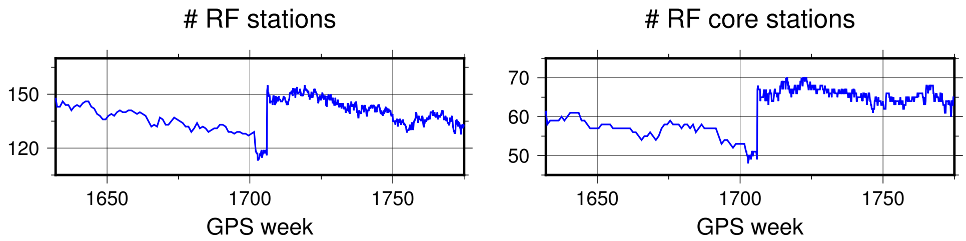

Figure 4: Numbers of usable RF stations and RF core stations in recent weekly/daily IGS combined SINEX solutions.

increase visible in Fig. 4 corresponds to the adoption of IGb08 on GPS week 1709 (October 7, 2012; IGSMAIL #6663). Since then, the overall number of usable RF stations has started decreasing again at a rather constant rate. In 2013, nine IGb08 stations thus became unusable as RF stations because of position discontinuities, seven of them due to equipment changes. Eleven other IGb08 stations were decommissioned or stopped transmitting data.

On the other hand, the number of RF core stations used to align the IGS daily combined solutions to IGb08 has fairly constantly remained around 65 during 2013. As illustrated in Fig. 5, the distribution of the usable IGb08 core stations was still rather satisfactory at the end of 2013, except two inevitable holes in South America/South Atlantic and Eastern Asia/North Pacific.

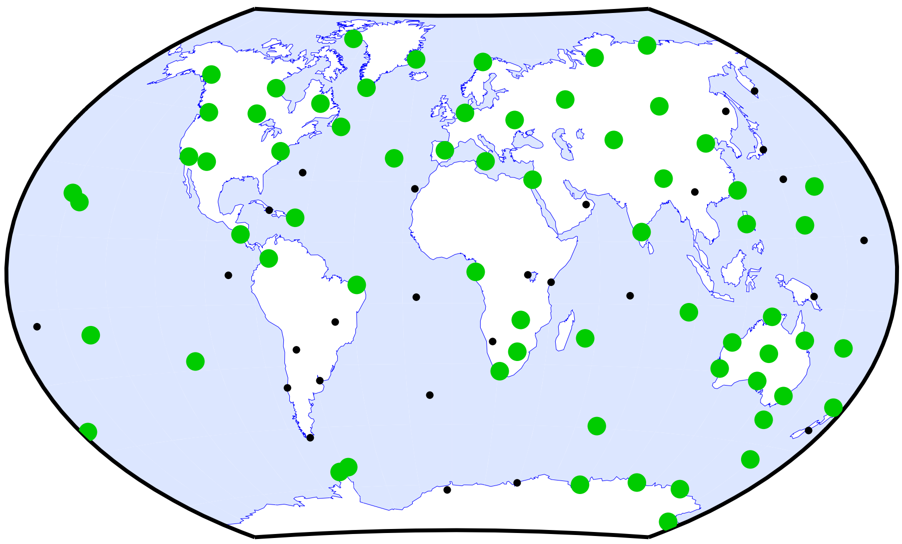

Figure 5: Distribution of the 64 IGb08 core stations used to align the IGS combined solution of December 31, 2013 (green dots). The small black dots correspond to the 27 other unusable IGb08 core stations.

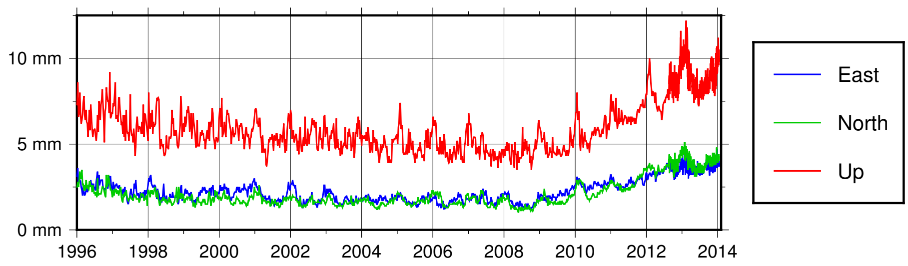

Figure 6: RMS of the residuals from 7–parameter similarity transformations between the weekly/daily IGS combined solutions and the IGS08/IGb08 Reference Frames. The *igb* weekly solutions (IGSMAIL #6401) were used for the period before GPS week 1632. The operational IGS combined solutions were used afterwards.

Fig. 6 finally illustrates another aspect of the progressive ageing of the IGS08/IGb08 Reference Frames. Since the latest IGS data inputs into ITRF2008 (2009.5), the accuracy of the IGS08/IGb08 reference station coordinates has indeed steadily degraded because of growing station velocity propagation errors. The global level of agreement between the IGS daily combined solutions and IGb08 is now at the level of 4 mm for horizontal station positions and 10 mm for station heights, about twice as in 2009. This growing disagreement is a concern for the accuracy and stability of the Reference Frame realized by the IGS products and will get worse until a new Reference Frame based on the future ITRF2013 is adopted.

4 Preparation of the 2nd IGS reprocessing campaign

One of the main motivations for the 2nd IGS reprocessing campaign (repro2) is to provide the IGS contribution to the next ITRF realization (ITRF2013). To make this contribution as strong and useful as possible, a set of recommended GNSS stations has been provided to the IGS ACs participating to repro2 (IGS–ACS–MAIL #849) along with several station selection guidelines reminded hereafter:

- Process all available IGb08 core stations to ensure a minimal common base between AC solutions in view of their combination.
- Avoid "jumping networks", i.e. radically different station selections from one day to the next.
- To the extent possible, include:
  - all available IGb08 stations;
  - all GNSS stations co–located with other techniques, including the co–located stations in ITRF2008 as well as some new or improved DORIS, SLR and VLBI

co–locations;

– the NGA stations, provided the availability of new data corrected for half–cycle phase offsets;

– specific stations selected in view of strengthening the next IGS Reference Frame in the South America, Pacific and Africa areas.

- Consider the inclusion of TIGA stations.

Several recommended non–IGS stations are already in the process of becoming part of the IGS network. Others have been submitted to the IGS Central Bureau in cooperation with the station operators.

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RINEX Working Group Report 2013

Ken MacLeod[1], Loukis Agrotis[2], and Rolf Dach[3]

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1 Introduction

The RINEX Working Group (RWG) was formed as a partnership between the IGS and the Radio Technical Commission for Maritime Services, Special Committee 104 (RTCM–SC104). Currently the working group consists of about 50 members with the numbers equally split between the two groups. Within the IGS, the RWG performs two roles: one is the development and documentation of the RINEX data format and the other is to work within the RTCM to develop messages and protocols that meet the needs of the IGS community.

2 Activities in 2013

In January of 2013, after several years of discussion and message content refinement, RTCM–SC104 approved the RTCM Multiple Signal Message (RTCM–MSM) binary format. The first release only supported: GPS, GLONASS and Galileo. However, QZSS and BeiDou support was added later in the year. The RTCM–MSM binary observation message format is fully interoperable with RINEX 3.02. Both RTCM–MSM and RINEX 3.02 use the same signal naming and phase alignment protocols. Further, all RTCM–MSM high precision observations types: pseudorange, phase, doppler, carrier to noise ratio and loss of lock, meet RINEX 3.0x measurement and protocol standards. The development of the RTCM–MSM format will enable GNSS users to either process binary data directly (file or internet stream) or convert the MSM binary format into RINEX 3.0x (without a loss of information). Lastly, at the May RTCM meeting the Galileo ephemeris message was approved.

In April of 2013 RINEX 3.02 was jointly released by the IGS/RTCM RINEX working group. RINEX 3.02 supports the following constellations: GPS, GLONASS, Galileo, QZSS, BeiDou and SBAS. As mentioned above RINEX 3.02 and RTCM–MSM observations both specify the same signal definition and phase alignment protocol. This level of integration and interoperability between RINEX and RTCM–MSM will make it easier to use both formats. Another new feature introduced in RINEX 3.02 is the specification of a new more descriptive file naming convention.

Summary of the RINEX working group's tasks completed in 2013:

- RTCM–MSM phase aligned binary observation format approved by the RTCM–SC104 (Jan. 2014)
  - RTCM–MSM currently supports GPS, GLONASS, Galileo, QZSS and BeiDou
- Released RINEX 3.02 in April of 2013. RINEX 3.02 supports the following GNSS constellations: GPS, GLONASS, Galileo, QZSS, BeiDou and SBAS.
- RTCM Galileo Ephemeris approved by RTCM.
- RINEX 3.02 is supported by GNSS equipment vendors and IGS partners (BKG's, BNC software). IGS analysis center support for RINEX 3.02 has started.
- The development of RINEX 3.02 Quality Control (QC) tools has begun. Some basic QC tools (multipath, cycle slip and percentage good data) are currently available.
- RINEX 3.02 interoperability testing is ongoing within the IGS MGEX project.
- In mid–November it was observed that some RINEX 3.02 providers were using the old RINEX 3.01 BeiDou B1 frequency codes. This inconsistency is currently being resolved within the MGEX project.
- Attended RTCM Meetings: January, 2013 (San Diego, CA), May, 2013 (Nante, France) (Loukis Agrotis) and September, 2013 (Nashville, TN)

3 Plan for 2014

During the 2014 calendar year the RINEX Working Group will focus its efforts on the following tasks:

- Update the RINEX 2.11 and 3.0X documentation to provide a clear and concise description of the standard to meet the needs of the GNSS community.
- Release a RINEX 3.02 update annually or as required.
- Support IGS partner and GNSS vendor adoption of RINEX 3.02.
- Further develop RINEX 3.02 QC tools.
- Work with both IGS and RTCM partners to test interoperability between RINEX

3.02 files created by different applications. Verify that RINEX 3.02 files are compliant with the standard i.e. contain mandatory records, properly defined records, correct codes and phase aligned observations.

- IGS RINEX 3.02 testing and development will be done as part of the IGS MGEX project.
- Planned additions to RINEX 3.0X include GPS CNAV ephemeris.

Within the RTCM–SC104 the RWG will contribute to the development of the following binary messages that would enable the creation of a complete RINEX file from either a GNSS receiver stream or an RTCM–MSM file:

- Station description (RINEX header information)
- Receiver description information such as: serial, model and firmware number and also state information such as: CPU load; internal temperature; number of satellite vehicles tracked and a station change control mechanism called: Issue of Data Station (IODS).
- Antenna Description: serial and model number and IODS.
- Meteorological Sensor Description and IODS.
- Meteorological Observations and IODS.
- The IODS is designed to notify both real–time and file based users that a station's equipment or software/firmware has changed and that the change may affect the usability of the observation data.

Other RTCM Messages:

- Extend RTCM–State Space Representation (RTCM–SSR), satellite orbit and clock correction messages to support Galileo, QZSS and BeiDou.

  – Develop RTCM–SSR messages to support atmospheric and ionospheric correction messages (both station and network types).
- Develop ephemeris messages to support QZSS, BeiDou and GPS(CNAV).
- Develop a position report message that contains position and accuracy (variance/covariance) information.

The IGS Tide Gauge Benchmark Monitoring Working Group

T. Schöne, R. Bingley, Z. Deng, J. Griffiths, H. Habrich, A. Hunegnaw, M. Jia, M. King, M. Merrifield, G. Mitchum, R. Neilan, C. Noll, E. Prouteau, L. Sánchez, N. Teferle, D. Thaller, P. Tregoning, G. Wöppelmann, and P. Woodworth

1 Introduction

In support of climate and sea level related studies and organizations concerned herewith, the Tide Gauge Benchmark Monitoring Working Group (TIGA–WG) of the IGS provides vertical geocentric positions, vertical motion and displacements of GNSS stations at or near tide gauges. To a large extend the TIGA–WG uses the infrastructure and expertise of the IGS.

The main aims of the TIGA Working Group are:

- Maintain a global virtual continuous GNSS @ TG network
- Compute precise coordinates and velocities of GNSS stations at or near tide gauges with a significant delay to allow as many as possible stations to participate. Provide a combined solution as the TIGA official product.
- Study the impacts of corrections and new models on the GNSS processing of the vertical coordinate. Encourage other groups to establish complementary sensors to improve the GNSS results, e.g., absolute gravity sites.
- Provide advice to new applications and installations.

For the year 2013, the TIGA–WG has continued to prepare the reprocessing of the TIGA network, which is in parallel to the repro2 campaign of the IGS. Test sets of data (weekly SINEX solutions) have been circulated between groups to ensure consistency in exchange formats. Four groups are currently reprocessing TIGA and GNSS@TG data (e.g., Deng et al. (2013), Hunegnaw et al. (2013)). Nearly 800 GNSS@TG stations and IGS08b core sites are processed. In peak times, e.g. GFZ (see Fig. 1) processes up to 794 stations, 580 of them near tide gauges. The numbers are similar for the other groups.

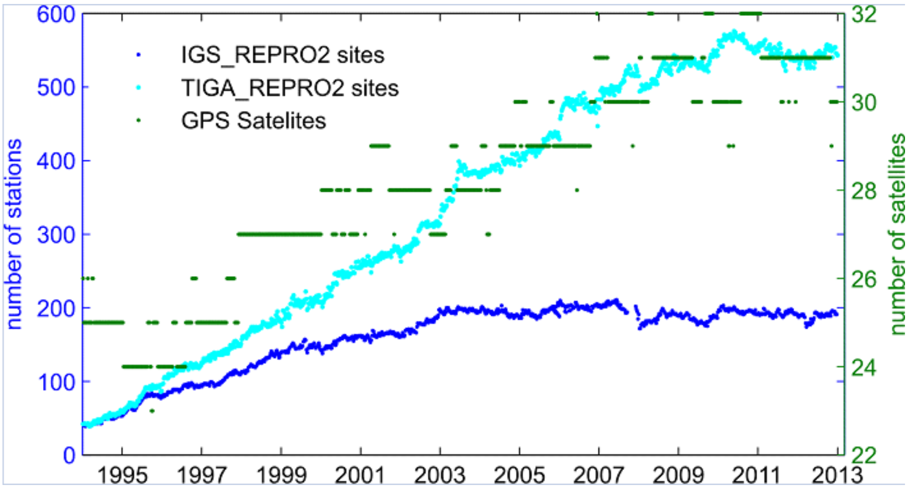

Figure 1: Number of GNSS@TG stations and number of satellites processed for the TIGA repro2 by GFZ Potsdam. At peak times nearly 800 GNSS stations are reprocessed.

Also significant progress has been made by the SONEL data center (http://www.sonel.org), hosted by the University of La Rochelle. The SONEL portal allows users to access meta data information, download data, and view processing results. Frequent updates and information exchange with TIGA Data Center hosted by NASA at CDDIS ensures up–to–date information.

As an ongoing task, SONEL in cooperation with the TIGA–WG identifies potential new TIGA stations and encourages and assists station manager to participate. In addition, stations with data outages and/or significant data gaps are identified. Station operators are contacted to get data access. The SONEL data center is recognized as the GNSS and TIGA data center for UNESCO/GLOSS/IOC. The progress is documented by, e.g., the growing number of archived RINEX files.

2 Recent TIGA related publications

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Olivares, G. and F.N. Teferle. A Bayesian Monte Carlo Markov Chain Method for Parameter Estimation of Fractional Differenced Gaussian Processes. *IEEE Transactions on Signal Processing*, 61(9):2405–2412, 2013.

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Sánchez, L.. Towards a vertical datum standardisation under the umbrella of Global Geodetic Observing System. *Journal of Geodetic Science*, 2(4):325–342, 2013. doi: 10.2478/v10156-012-0002-x.

Santamaría–Gómez, A., M–N. Bouin, X. Collilieux, and G. Wöppelmann. Time–Correlated GPS Noise Dependency on Data Time Period. *International Association of Geodesy Symposia*, 138:119–124, 2013.

Santamaría–Gómez, A., M–N. Bouin, and G. Wöppelmann. Improved GPS data analysis strategy for tide gauge benchmark monitoring. *International Association of Geodesy Symposia*, 136:11–18, 2012.

Schöne, T., R. Bingley, Z. Deng, J. Griffiths, H. Habrich, A. Hunegnaw, ,M. Jia, M. King, M. Merrifield, G. Mitchum, R. Neilan, C. Noll, E. Prouteau, L. Sánchez, N. Teferle, D. Thaller, P. Tregoning, P. Woodworth, and G. Wöppelmann. The Tide Gauge Benchmark Monitoring Project. In: Dach and Jean (eds.): Technical Report 2012, International GNSS Service, pp. 189–194, ftp://igs.org/pub/resource/pubs/2012_techreport.pdf, 2013.

Schöne, T.. GNSS at Tide Gauges, German Climate Observing Systems. Inventory report on the Global Climate Observing System, (GCOS)Self–published by DWD, Offenbach a. M., 130 pages.

Deng, Z., G. Gendt., and T. Schöne. Status of the tide Gauge data reprocessing at GFZ. *International Association of Geodesy Scientific Assembly*, 150th Anniversary of the IAG, Potsdam, 1.–6. Sep., 2013.

Hunegnaw, A., F.N. Teferle, R.M. Bingley, and D.N. Hansen. Status of Reprocessing and Combinations of TIGA Analysis Center Solutions at BLT. *IAG Scientific Assembly 2013*, IAG 150 Years, 1–6 September, Potsdam, Germany, 2013.

3 TIGA Working Group Members in 2013

Table 1: TIGA Working Group Members in 2013

Name	Entity	Host Institution	Country
Guy Wöppelmann	TAC, TNC, TDC	University La Rochelle	France
Laura Sánchez	TAC	DGFI Munich	Germany
Heinz Habrich	TAC	BGK, Frankfurt	Germany
Minghai Jia		GeoScienceAustralia	Australia
Paul Tregoning	TAC	ANU	Australia
Zhiguo Deng	TAC	GFZ Potsdam	Germany
Daniela Thaller	Combination	BGK, Frankfurt	Germany
Norman Teferle	TAC/Combination	University of Luxembourg	Luxembourg
Richard Bingley	TAC	University of Nottingham	UK
Ruth Neilan	IGS Central Bureau	ex officio	USA
Jake Griffith	IGS AC coordinator	ex officio	USA
Carey Noll	TDC	CDDIS, NASA	USA
Tilo Schöne	Chair TIGA–WG	GFZ Potsdam	Germany
Philip Woodworth	PSMSL	PSMSL, Liverpool	UK
Gary Mitchum	GLOSS GE (current chair)	University of South Florida	USA
Mark Merrifield	GLOSS GE (past chair)	UHSLC, Hawaii	USA
Matt King		University of Tasmania	Australia

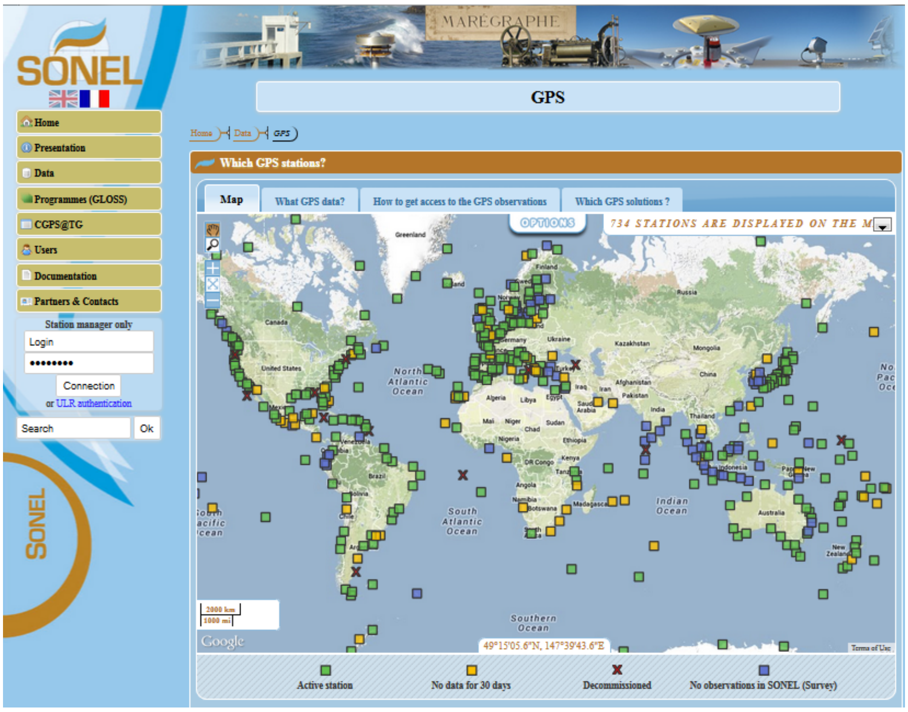

Figure 2: The SONEL TIGA data center (University La Rochelle, France) provides an access point for meta information (http://www.sonel.org). The GNSS data base is synchronized with the TIGA Data Center (TDC) at CDDIS (NASA, USA). In addition, informations are exchanged and updated with the PSMSL (http://www.psmsl.org) and GLOSS data centers (e.g., http://www.ioc-sealevelmonitoring.org).

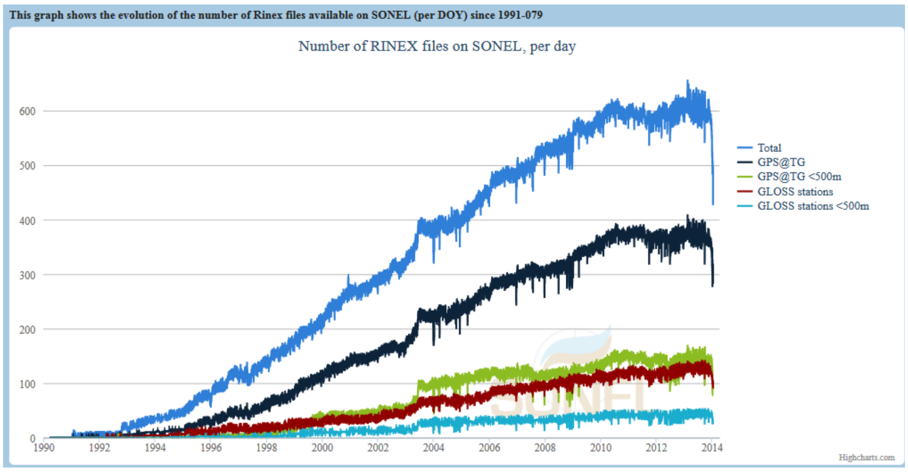

Figure 3: Development of the number of RINEX files for GNSS@TG available trough the SONEL data center.

IGS Troposphere Working Group 2013

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1 Introduction

The IGS Troposphere Working Group (IGS TWG) was founded in 1998. The United States Naval Observatory (USNO) assumed chairmanship of the WG as well as responsibility for producing IGS Final Troposphere Estimates (IGS FTE) in 2011.

Dr. Christine Hackman chairs the IGS TWG. Dr. Sharyl Byram oversees production of the IGS FTEs. Both are part of the GPS Analysis Division (GPSAD) in the Earth Orientation Department at USNO. GPSAD also hosts the USNO IGS Analysis Center.

The IGS TWG comprises approximately 50 members (cf. Appendix A.). A revised charter approved by the IGS Governing Board (GB) at the close of 2011 is shown in Appendix B.

2 IGS Final Troposphere Product Generation/Improvements/Usage 2013

USNO produces IGS Final Troposphere Estimates for the 350+ stations of the IGS network. Each 24–hr site result file provides five–minute–spaced estimates of total troposphere zenith path delay (ZPD), north, and east gradient components, with the gradient components used to compensate for tropospheric asymmetry. These files can be downloaded from ftp://cddis.gsfc.nasa.gov/gps/products/troposphere/zpd; users downloaded 10.3 million files in 2013 (Noll 2014).

IGS Final Troposphere estimates are generated via *Bernese GPS Software* 5.0 (Dach et al. 2007) using precise point positioning (PPP; Zumberge et al. (1997)) and the GMF mapping function (Boehm et al. 2006) with IGS Final satellite orbits/clocks and earth orientation parameters (EOPs) as input. Each site–day's results are completed approximately three weeks after measurement collection as the requisite IGS Final orbit products become available. Further processing details can be obtained from Byram and Hackman (2012). USNO will use *Bernese GNSS Software* 5.2 (http://www.bernese.unibe.ch/features) to compute troposphere estimates for the IGS Reprocessing 2 effort (http://acc.igs.org/reprocess2.html).

Several improvements in quality–control and number of stations processed were made in 2013. An error in implementing antenna–height changes was corrected with the affected station–days reprocessed and re–archived (Hackman 2013). Detection of missing input data and result outliers was strengthened; faster raw–data download and result upload routines were implemented as well. The average number of quality–checked station result files submitted per day in 2013 thus improved 7% to 324 from its 2012 average value of 302. The authors thank Drs. James Perlt (Bundesamt fuer Kartographie & Geodaesie) and Jan Dousa (Geodetic Observatory Pecny; GOP) for alerting them to quality–control issues.

3 IGS Troposphere Working Group Activities 2013

3.a Automating comparisons of troposphere estimates obtained using different measurement techniques

At the 2012 IGS Workshop (Olstzyn, Poland), the IGS TWG submitted the following recommendation to the IGS Governing Board, which accepted it:

"By the next [2014] IGS Workshop, establish automated, on–going comparison of IGS final troposphere estimates (FTEs) with results from other techniques/ACs with the goal of establishing the accuracy of IGS FTEs."

- Jan Dousa and his GOP colleagues developed a database performing the desired comparisons between troposphere values obtained from different techniques such as GPS, VLBI, radiosonde and numerical–weather models. This database is flexible enough to handle additional data types as desired.
- Comparison of troposphere values from different techniques requires an understanding of the exact point in space to which a given estimate corresponds. Several such potential inter–technique reference–point discrepancies have been resolved.
- It was originally proposed (Byram and Hackman 2012) that corrections applied to non–co–located troposphere estimates be performed using equations given in Teke et al. (2011). Dousa and colleagues have developed further refinements (Gyori and Dousa 2014) that will likely be used instead.

3.b Other activities

- A joint US–Czech grant proposal, "Automated Intra– and Inter–technique Troposphere Estimate Comparisons," was made to the Kontact II Czech–US research partnership by GOP's Jan Dousa with supporting documents authored by USNO/WG chair Christine Hackman. The US Department of State is the executive agent.
- A variety of future initiatives were discussed at the 10 December 2013 working–group meeting: please see Section 3.c.2 below.

3.c 2013 working–group meetings and associated future initiatives

The IGS TWG presently meets twice per year: once in the spring/summer at either the European Geosciences Union (EGU) meeting or the IGS Workshop, and once at the American Geophysical Union Fall Meeting (December). 2013 meetings were as follows:

3.c.1 5 June 2013:

The chair was unable to travel to Europe in Spring 2013, causing the WG to conduct its first–ever online–only meeting 5 June 2013 courtesy of the IGS gotomeeting.com membership. Presentations were made on a) WG business and progress on automating the troposphere estimate comparisons (C. Hackman), b) tropo–comparison database development at GOP (J. Dousa) and c) the COST[1] GNSS4SWEC initiative (G. Guerova, Univ. Sofia).

3.c.2 10 December 2013, San Francisco, CA (with gotomeeting.com coverage):

Presentations were made by a) C. Hackman (WG business, updates on tropo–comparison project), and b) J. Dousa (details of the tropo–comparison project), with c) a paper and presentation by D. Sguerso's Univ. of Genoa group on their 14–year set of troposphere delays for the French–Italian border region submitted as a contribution to the meeting as well.

This meeting included lively discussion on a variety of new/old topics as well:

Re–establishment of comparison of IGS analysis–center troposphere estimates with IGS Final Estimates:

Comparison of troposphere estimates computed at IGS analysis centers to the IGS Final Estimates has been discontinued for several years. Discussions at this meeting indicated that there is significant interest in re–establishing these comparisons. Action on this will therefore be forthcoming.

[1] COST: European Cooperation in Science and Technology; http://www.cost.eu

Standardization of "tropo_sinex" format: The sinex_tro ver. 0.01 format originally proposed in 1997 for distribution of IGS troposphere values (http://igscb.jpl.nasa.gov/igscb/data/format/sinex_tropo.txt) was not a "true" SINEX format: while some blocks were borrowed from SINEX, non–SINEX blocks were introduced as well.

This format was unofficially adopted/put into use and later extended to accommodate troposphere gradients, but meanwhile, other space–geodesy techniques had adopted the format and not all technique communities named gradient (and other) parameters the same way. For example, while the IGS uses N/E gradient labels TGNTOT/TGETOT as well as STDEV, VLBI uses GRN_EST/GRE_EST, and STDDEV (note extra "D"), e.g., http://ivs.nict.go.jp/mirror/products-data/sinex_v2_trop.txt

IGS TWG action toward officially standardizing/adopting *some* troposphere SINEX–like format was proposed informally several times in 2013 due to (a) development of the automated tropo–comparison database and (b) COST GNSS4SWEC/EUREF initiatives toward addressing the problem.

Attendees of the 10 December 2013 IGS TWG meeting agreed that while the WG needs to take action on this, it also would be wise to finish one large project (the automated tropo–comparison database) before beginning another. It is likely that this matter will therefore be discussed in light of "Should this be the next big WG project?" at the 2014 IGS Workshop.

Repro 2 troposphere estimates, day–boundary discontinuities, and meteorology/ climate–change–community needs:

Repro 2 troposphere processing has not yet begun because it will be performed using PPP and must therefore await completion of the Repro 2 orbits/clocks/EOPs. The meteorology/climate–change user community, e.g., COST GNSS4SWEC WG3, plans to use Repro 2 troposphere values for their research and is thus interested in Repro 2 estimate quality. The day–boundary discontinuities in troposphere estimates associated with the IGS–prescribed 24–hour processing window create problems for the meteo community. A vigorous discussion of IGS standards vs meteo–community needs thus ensued at the 10 December 2013 TWG meeting.

The meteo and IGS parties agreed to continue working together on this since no one present knew how to create a win–win solution. *IGS President Urs Hugentobler has since volunteered to assign a bachelors–thesis project of studying the discontinuities in IGS troposphere estimates.* His assistance is gratefully acknowledged.

4 Presentations Contributed to Working–Group Meetings

The following can be obtained by contacting the lead author of this report:

5 June 2013:

- J. Dousa and G. Gyori. GOP Tropo Database. 11 pp.
- C. Hackman. IGS TWG Meeting. 43 pp.
- J. Jones, G. Guerova, O. Bock, S. de Haan, G. Dick, J. Dousa, G. Elgered, R. Pacione, E. Pottiaux, and H. Vedel. Advanced GNSS Tropospheric Products for Monitoring Severe Weather Events and Climate (GNSS4SWEC). Originally presented at COST Earth System Science and Environmental Domain Committee Hearing 17 September 2012. 30 pp.

10 December 2013:

- J. Dousa. GOP–TropDB: IGS TropoWG – Progress Report. 7 pp.
- C. Hackman. IGS Troposphere Working Group Meeting. 13 pp.
- G. Agrillo, B. Federici, L. Labbouz, D. Sguerso, and A. Walpersdorf. A Space–Temporal Monitoring of ZTD Parameters on 14 Years in French–Italian Neighbouring Area. Originally presented at the VIII Hotine–Marussi Sympsium, Rome, June 2013. 43 pp.
- D. Sguerso, L. Labbouz, and A. Walpersdorf. 14 Years of GPS Tropospheric Delays in the French–Italian Border Region: a Data Base for Meteorological and Climatological Analyses. 8 pp.

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Zumberge, J. F., M. B. Heflin, D. C. Jefferson, M. M. Watkins, and F. H. Webb. Precise Point Positioning for the Efficient and Robust Analysis of GPS Data from Large Networks. *J. Geophys. Res.*, 102(B3):5005–17, 1997.

Appendix A. IGS Troposphere Working Group Members

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Ahmed	Furqan	Universite du Luxembourg	Luxembourg
Amirkhani	Mohammad	Islamic Azad Univ. Tehran	Iran
Bar–Sever	Yoaz	Jet Propulsion Laboratory (JPL)	USA
Bevis	Mike	Ohio State University	USA
Bosser	Pierre	ENSG/DPTS	France
Bosy	Jaroslaw	Institute of Geodesy and Geoinformatics; Wroclaw University of Environmental and Life Sciences	Poland
Braun	John	UCAR	USA
Byram	Sharyl	USNO	USA
Byun	Sung	JPL	USA
Calori	Andrea	Univ. Roma La Sapienza	Italy
Chen	Junping	Shanghai Astronomical Observatory	China
Colosimo	Gabriele	Univ. Roma La Sapienza	Italy
Crespi	Mattia	Univ. Roma La Sapienza	Italy
Dick	Galina	GFZ	Germany
Dousa	Jan	GOP	Poland
Drummond	Paul	Trimble	USA
Ghoddousi–Fard	Reza	Natural Resources Canada	Canada
Guerova	Guergana	Univ. Sofia	Bulgaria
Gutman	Seth	NOAA	USA
Hackman	Christine	USNO	USA
Heinkelmann	Robert	GFZ	Germany
Herring	Tom	MIT	USA
Hilla	Steve	NGS/NOAA	USA
Hobiger	Thomas	Natl. Inst. of Info. & Comm. Tech. (NICT)	Japan
Jones	Jonathan	Met Office UK	UK
Langley	Richard	Univ. New Brunswick	Canada
Leighton	Jon	3vGeomatics	Canada/UK
Liu	George	Hong Kong Polytechnic University	Hong Kong
Moeller	Gregor	TU Wien	Austria
Moore	Angelyn	JPL	USA
Negusini	Monia	Inst. Radioastronomy (IRA); National Inst. Astrophysics (INAF)	Italy
Nordman	Maaria	Finnish Geodetic Inst.	Finland
Pacione	Rosa	ASI/CGS	Italy
Penna	Nigel	Univ. Newcastle	UK
Perosanz	Felix	CNES	France
Pottiaux	Eric	Royal Obs Belgium	Belgium
Prikryl	Paul	Communications Research Centre, Canada	Canada
Rocken	Chris	GPS Solutions	USA
Santos	Marcelo	Univ. New Brunswick	Canada
Schaer	Stefan	AIUB	Switzerland
Schoen	Steffen	Inst. Erdmessung, Leibniz Uni Hannover	Germany
Sguerso	Domenico	Lab. Geodesy, Geomatics, GIS; Univ. Genoa	Italy
Soudarin	Laurent	Collecte Localisation Satellites	France
Teferle	Norman	Universite du Luxembourg	Luxembourg
Tracey	Jeffrey	USNO	USA
van der Marel	Hans	TU Delft	Netherlands
Wang	Junhong	UCAR/NCAR	USA
Willis	Pascal	Inst. de Physique du Globe de Paris	France
Xu	Zong–qiu	Liaoning TU	China
Zhang	Shoujian	Wuhan Univ.	China

Appendix B. IGS Troposphere Working Group Charter

IGS TROPOSPHERE WORKING GROUP CHARTER

GNSS can make important contributions to meteorology, climatology and other environmental disciplines through its ability to estimate troposphere parameters. Along with the continued contributions made by the collection and analysis of ground–based receiver measurements, the past decade has also seen new contributions made by space–based GNSS receivers, e.g., those on the COSMIC/FORMOSAT mission [1]. The IGS therefore continues to sanction the existence of a Troposphere Working Group (TWG).

The primary goals of the IGS TWG are to:

- Assess/improve the accuracy/precision of IGS GNSS–based troposphere estimates.
- Improve the usability of IGS troposphere estimates.

  o Confer with outside agencies interested in the use of IGS products.

  o Assess which new estimates should be added as "official" IGS products, and which, if any, official troposphere product sets should be discontinued.
- Provide and maintain expertise in troposphere–estimate techniques, issues and applications.

Science background

The primary troposphere products generated from ground–based GNSS data are estimates of total zenith path delay and north/east troposphere gradient. Ancillary measurements of surface pressure and temperature allow the extraction of precipitable water vapor from the total zenith path delay.

Water vapor, a key element in the hydrological cycle, is an important atmosphere greenhouse gas. Monitoring long–term changes in its content and distribution is essential for studying climate change. The inhomogeneous and highly variable distribution of the atmospheric water vapor also makes it a key input to weather forecasting.

Water vapor distribution is incompletely observed by conventional systems such as radiosondes and remote sensing. However, ground– and space–based GNSS techniques provide complementary coverage of this quantity. Ground–based GNSS observations produce continuous estimates of vertically integrated water vapor content with high temporal resolution over a global distribution of land–based locations; coverage is limited over the oceans (where there is no land). Conversely, water vapor can be estimated from space–borne GNSS receivers using ray tracing techniques, in which case solutions with high vertical resolution (laterally integrated over few hundred kilometers) and good oceanic/land coverage are obtained; these solutions however are discontinuous in geographic location and time.

Be it resolved that the IGS troposphere WG will:

- Support those IGS analysis centers providing official IGS troposphere products.
- Increase awareness/usage of IGS troposphere products by members of the atmospheric, meteorology and climate–change communities. Solicit the input and involvement of such agencies.
- Create new IGS troposphere products as needed (as determined by consultation with the potential user community).
- Determine the uncertainty of IGS troposphere estimates through comparison of solutions with those obtained from independent techniques, or through other means as appropriate.
- Promote synergy between space–based and ground–based GNSS techniques through interaction with researchers in both fields.

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